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Effect of Temperature-Humidity Index on Live Performance in Broiler Chickens Grown From 49 To 63 Days of Age

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Abstract. *The thermal environment in poultry housing is a primary influence on production efficiency and live performance. Heavy broilers (body weight > 3.2 kg) typically require high ventilation rates to maintain thermal comfort and production efficiency. However, large birds are observed to pant in mild to moderate thermal conditions, indicating that upper critical temperatures may be lower at larger body weights. Thermal comfort indices such as the temperature-humidity index (THI) integrate the effects of temperature and humidity and may offer a means to predict the effects of thermal conditions on performance. The objective of this study was to determine live performance of heavy broilers over a range of dry-bulb temperature (15°C, 21°C, and 27°C) and relative humidity (50%, 65%, and 80%), hence THI (14.8°C to 26.9°C). A series of four studies were completed with broiler chickens housed in environmental chambers. Live performance parameters including body weight, body weight gain, feed intake, and feed conversion ratio were compared; body temperature was measured in three birds of each treatment during one study. Results show that as THI exceeds approximately 21°C, bird performance significantly declined and body temperature increased up to 1.7°C above nominal body temperature for broilers (41°C). Regression analysis showed that a quadratic relationship exists between THI and the four performance parameters of interest. Prediction accuracy was decreased due to variability in the data and suggests data at additional THI points are necessary.*

Keywords. Poultry, housing, heat stress, ventilation

Introduction

The thermal environment is a controlling factor in energy metabolism and exchange. Mitigating heat or cold stress improves animal health, well-being, and production efficiency. To this end, thermal comfort indices such as temperature-humidity index (THI) have been developed to assess the impact of the thermal environment on thermoregulatory status of animals. Thermal comfort indices are species dependent and have been developed for humans (Thom, 1958), dairy cattle (Buffington et al., 1981), swine (Ingram, 1964), turkeys (Xin et al., 1992; Brown-Brandl et al., 1997), and laying hens (Zulovich and DeShazer, 1990; Tao and Xin, 2003). With the exception of Zulovich and DeShazer (1990), the development of THI has been based upon body temperature responses, rather than production responses.

The THI equations developed for poultry to date are shown in equations 1 through 4. With the exception of tom turkeys (Brown-Brandl et al., 1997), the dry-bulb weighting factor exceeds the wet-bulb weighting factor.

$$THI_{broilers} = 0.85\ T_{db} + 0.15\ T_{wb} \qquad \text{(1, Tao and Xin, 2003)}$$

$$THI_{layers} = 0.6\ T_{db} + 0.4\ T_{wb} \qquad \text{(2, Zulovich and DeShazer, 1990)}$$

$$THI_{hen\ turkeys} = 0.74\ T_{db} + 0.26\ T_{wb} \qquad \text{(3, Xin et al., 1992)}$$

$$THI_{tom\ turkeys} = 0.42\ T_{db} + 0.58\ T_{wb} \qquad \text{(4, Brown-Brandl et al., 1997)}$$

where: THI = temperature-humidity index, °C

T_{db} = dry-bulb temperature, °C

T_{wb} = wet-bulb temperature, °C

Thermal comfort indices have also been evaluated as a predictor of production efficiency in dairy cattle using THI (Cargill and Stewart, 1966; Johnson et al., 1962, 1963) and black globe humidity index (BGHI) (Buffington et al., 1981), and also in swine (Ingram, 1965; Roller and Goldman, 1969), laying hens (Zulovich and DeShazer, 1990), and broilers (Chepete et al., 2005). Chepete et al. (2005) developed THI relationships for broilers based on production parameters in naturally ventilated housing in a semi-arid climate throughout the production cycle, but it has limited application in heavy (> 3.2 kg) broilers reared for breast meat production.

Broilers reared for breast meat production are heavier at market weight (3.8 kg) as compared to those for retail (2.4 kg) and restaurant markets (1.8 kg). Additional cooling is typically achieved through increased air velocity in tunnel ventilation systems (Dozier et al., 2005a, 2005b,2006) which enhances dissipation of sensible heat through convection (Simmons et al., 1997). However, the inter-relationship between air velocity, humidity, and air temperature remains undefined and producers may not adjust ventilation controls to operate at increased capacity when thermal conditions are considered acceptable.

Dozier et al. (2007) observed heavy broilers panting at air temperatures that were within what is considered to be the thermoneutral zone (TNZ) of the broiler (21.1°C). Panting reduces production efficiency as metabolic energy is diverted from growth and development to maintaining homeothermy. Current estimate of TNZ (and associated upper and lower critical temperatures – UCT, LCT) of chickens may not be applicable to heavy broilers and requires further investigation. Better understanding of the production responses under varied thermal environments would allow for predictive control to limit thermal stress and production declines. Therefore, the objective of this research was to assess the relationship between THI and live performance metrics in heavy broiler chickens.

Materials and Methods

A series of four trials was conducted in environmental chambers, involving THI values ranging from 14.7°C to 26.3°C (table 1). The THI values resulted from a 3 × 3 factorial arrangement of dry-bulb air temperature (T_{db}, 15°C, 21°C, and 27°C) and relative humidity (RH, 50%, 65%, and 80%). Fifty broiler chickens (25 males and 25 females, Ross × Ross 708) were placed in each of nine environmental chambers on the day of hatch. The broilers were reared under a common thermoneutral temperature program until day 42, at which point T_{db} was gradually increased or decreased to its final setpoint at day 49 and was held till day 63. RH was held constant at 50% until day 42, and was gradually adjusted with temperature until reaching the treatment setpoint at day 49. Body weight (BW) data were obtained on days 49 and 63; feed intake (FI) data were collected throughout the test period. Mortalities were weighed and recorded daily. Body weight gain (BWG) and feed conversion ratio (FCR) were calculated from measured parameters.

Table 1. Air temperature and relative humidity setpoints for live production trials.

Treatment	T_{db} (°C)	RH (%)	T_{wb} (°C)	THI[a] (°C)
A	15.6	50	10.2	14.8
B	15.6	65	11.9	15.0
C	15.6	80	13.6	15.3
D	21.1	50	14.7	20.1
E	21.1	65	16.8	20.5
F	21.1	80	18.7	20.7
G	27.0	50	19.3	25.8
H	27.0	65	21.7	26.2
I	27.0	80	24.0	26.6

[a]THI = $0.85 \times T_{db} + 0.15 \times T_{wb}$

Core body temperature (CBT) was measured in one trial using miniature temperature data loggers (DS1922L, Maxim, Sunnyvale, Cal.) with a published accuracy of 0.5°C and resolution of 0.0625°C. Loggers were calibrated in a waterbath; standard errors of calibration regressions were less than 0.001°C over the range of 35°C to 45°C. Loggers were placed at 59 days of age per the method described by Brown-Brandl et al. (2003), namely, a logger was placed behind the tongue in the mouth so that the bird could swallow it with ease. Three birds per treatment were instrumented for CBT measurement. Loggers typically moved into the gizzard within two hours, as assessed by changes in temperature when birds drank. Temperature was measured at 2 min intervals over the final 5 d of production. Loggers were recovered from the gizzard at the processing plant for data retrieval. All procedures were approved by the Animal Care and Use Committee at the USDA-ARS Mississippi State Location.

Statistical Analysis

The THI developed for broilers (equation 1, Tao and Xin, 2003) was used for all comparisons. Given the differing genetics and body conformation of layers and turkeys, those THI values were not used for this analysis.

Live Performance

The following live performance parameters were analyzed to determine differences between treatments: mean BW, mean BWG, mean FI, and FCR. Data were analyzed using PROC MIXED in PC-SAS using temperature-humidity combinations as the main effect, with trial and trial × treatment as random effects. Least squares means were separated using Fisher's LSD (Ott and Longnecker, 2009) and significance was considered at P ≤ 0.05.

Core body temperature (CBT)

Four days (days 60-63) of CBT data were used for analysis. Hourly CBT was analyzed using a repeated measures analysis with PROC MIXED in PC-SAS, with hour as the repeated factor in this analysis. Means were separated using Fisher's LSD (Ott and Longnecker, 2009) and significance was considered at P ≤ 0.05.

Performance Prediction using THI

Regression analysis was used to determine the relationship between THI and live performance. SigmaPlot (v8.0, Systat Software, Inc., San Jose, CA) was used for the analysis.

Results and Discussion

THI was found to have significant impact on production responses of the broilers. Specifically, BW, BWG, and FI all significantly decreased as THI increased (table 2), while FCR increased substantially as THI exceeded 20.7°C.

Table 2. Mean production response of broilers from 49 to 63 days. Table values represent least squares means with associated standard errors for body weight (BW), body weight gain (BWG), feed intake (FI), and feed conversion ratio (FCR) for the experimental period.

Treatment	n	THI (°C)	BW[a] (g)	BWG (g)	FI (g)	FCR (g:g)
A	4	14.8	4517 ± 57 ab	1078 ± 63 a	3109 ± 107 a	2.77 ± 0.81 c
B	3	15.0	4474 ± 61 abc	1032 ± 68 a	2942 ± 68 ab	2.87 ± 0.83 c
C	2	15.3	4547 ± 68 a	1060 ± 75 a	3082 ± 129 a	2.76 ± 0.95 c
D	3	20.1	4382 ± 61 bcd	963 ± 68 ab	2898 ± 115 ab	3.07 ± 0.83 c
E	4	20.5	4305 ± 55 d	841 ± 61 b	2792 ± 107 b	3.18 ± 0.79 c
F	3	20.7	4350 ± 57 cd	929 ± 63 ab	2827 ± 107 b	2.99 ± 0.75 c
G	3	25.8	4071 ± 61 e	584 ± 67 c	2367 ± 115 c	4.01 ± 0.81 bc
H	4	26.2	3873 ± 58 f	337 ± 65 d	2168 ± 107 c	6.00 ± 0.77 a
I	4	26.6	4035 ± 60 e	475 ± 67 c	2322 ± 107 c	4.71 ± 0.80 ab
P-value			< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a]Table values represent least squares means ± standard error of the mean and were separated using Fisher's LSD. Means within a column with no common superscripts differ significantly (P ≤ 0.05).

CBT significantly increased with THI (table 3), and differences between daily maximum and minimum means ranged from 1.1°C to 1.2°C. Equipment failure caused poor temperature control during the trial where CBT was measured, and as such, no CBT data are available for treatment C (THI = 15.3°C).

Table 3. Daily mean body temperatures for each THI treatment. Values represent least squares means body temperatures of *n* samples.

Treatment[a]	THI (°C)	BW[b] (g)	n	Day 60[c] (°C)	Day 61 (°C)	Day 62 (°C)	Day 63 (°C)
A	14.8	4733	3	41.39 ± 0.04[e]	41.53 ± 0.04[g]	41.51 ± 0.04[e]	41.42 ± 0.03[f]
B	15.0	4491	2	41.68 ± 0.04[d]	41.69 ± 0.04[f]	41.71 ± 0.05[d]	41.71 ± 0.04[e]
D	20.1	4343	2	42.16 ± 0.04[c]	42.13 ± 0.04[d]	42.17 ± 0.05[b]	42.15 ± 0.04[c]
E	20.5	4239	3	41.75 ± 0.04[d]	41.85 ± 0.04[e]	41.85 ± 0.04[c]	41.74 ± 0.03[de]
F	20.8	4404	3	41.78 ± 0.04[d]	41.78 ± 0.04[ef]	41.87 ± 0.04[c]	41.81 ± 0.03[d]
G	25.9	3992	3	42.63 ± 0.04[a]	42.70 ± 0.04[a]	42.63 ± 0.04[a]	42.40 ± 0.03[b]
H	26.3	3976	3	42.41 ± 0.04[b]	42.52 ± 0.04[b]	42.56 ± 0.05[a]	42.52 ± 0.04[a]
I	26.6	4007	3	42.31 ± 0.04[b]	42.40 ± 0.04[c]	42.27 ± 0.04[b]	42.19 ± 0.03[c]
P-value				< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a]Equipment failure during this trial resulted in loss of temperature control for treatment C, and these data were excluded from this analysis.
[b]Three birds per treatment were instrumented with temperature loggers. Logger failure in two birds reduced the number of birds included in this analysis for treatments B and D.
[c]Table values represent least squares means ± standard error of the mean and were separated using Fisher's LSD. Means within a column with no common superscripts differ significantly (P ≤ 0.05)

Regression analysis showed that generally, quadratic relationships existed between THI and live performance parameters. As seen in figures 1 through 4, significant variation existed in live performance within treatments and across trials. Regression results are shown in table 4. Correlation coefficients (R^2) exceed 0.75 for BW, BWG, and FI; the variation in live performance as THI > 20.8°C reduced R^2 to 0.569, indicating the need for more data to improve the model. Accuracy of prediction, as assessed with the standard error of the regression, also shows that additional data are necessary to reduce error, especially for THI > 20.8°C

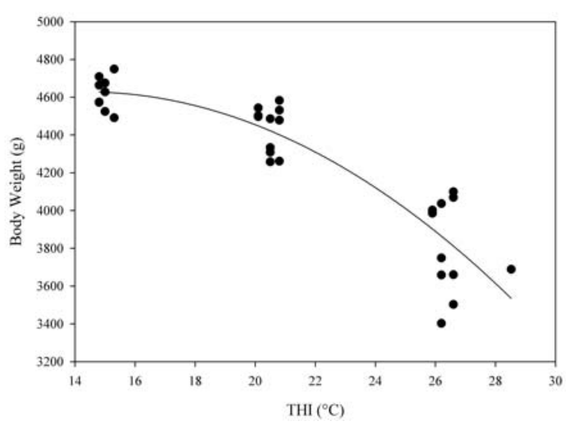

Figure 1. Final body weight at 63 d.

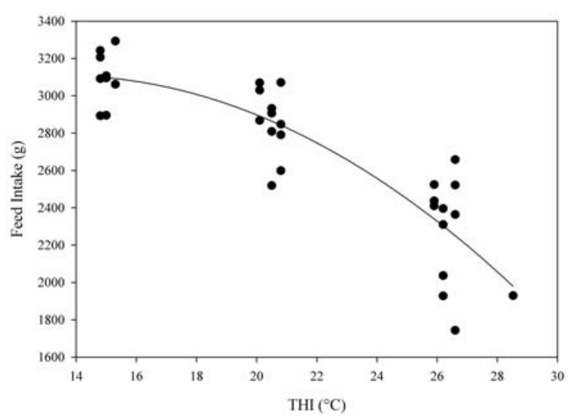

Figure 2. Feed intake over experimental period.

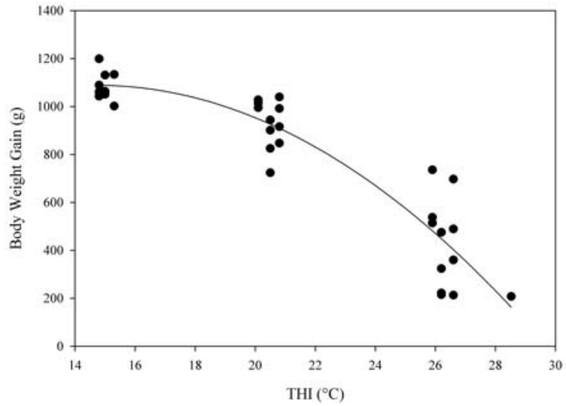

Figure 3. Body weight gain over experimental period.

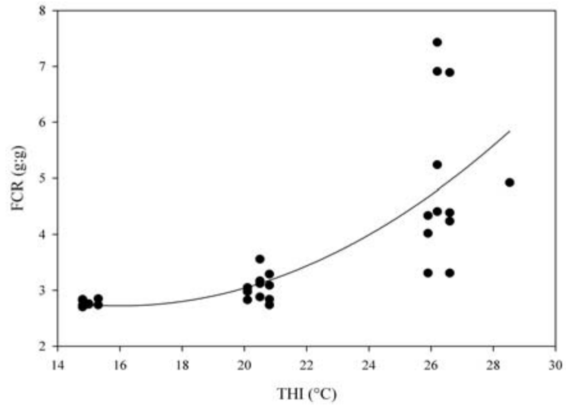

Figure 4. Feed conversion ratio for experimental period.

Table 4. Results of regression analysis depicting relations between THI and live performance parameters of heavy broilers (BW = body weight, BWG = BW gain, FI = feed intake, FCR = feed conversion ratio).

Parameter	**THI**		**THI^2**		**Intercept**		**SER**	**R^2**
	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
BW	156.1	0.0480	-5.44	0.0051	3509	<0.0001	167.8	0.824
BWG	143.3	0.0158	-4.87	0.0010			124.0	0.860
FI			-50.2	0.0306	2189	0.0267	206.1	0.768
FCR			0.02	0.0459			0.89	0.569

The production declines observed in this study illustrate the need to re-evaluate critical temperatures for broiler chickens to more accurately define their TNZ. As noted previously, Dozier et al. (2007) observed heavy broiler chickens panting at 21.1°C; improved definition of critical temperatures will allow for specification of improved control algorithms to maintain thermal comfort and production efficiency. Figures 1 through 4 suggest that a critical THI exists between 20°C and 26°C where additional efforts to cool the birds through air velocity or evaporative cooling are necessary to prevent thermal stress and maintain productivity. Given the observations by Dozier et al. (2007), pre-emptive cooling measures such as tunnel ventilation at night (Dozier et al., 2006) at lower THI may offset negative effects of elevated THI during the day. Continued activation of cooling based on longer-term average conditions, rather than current conditions, have been used to automate this approach but without use of TIV (time integrated variable) control to date (Timmons et al., 1995).

Xin et al. (2001) found no differences in total specific heat production for body weights above 2.3 kg up to 3 kg; however latent heat production was decreased, necessarily resulting in increased sensible heat production. Given the increased sensible heat production and that poultry are most affected by sensible rather than latent heat loss, heavy broilers produced from modern genetic strains will require lower air temperatures to optimize production efficiency. Broilers are most dependent upon sensible heat loss to maintain homeothermy, and this can be increased via air movement. Tao and Xin (2003) developed a temperature-humidity-velocity index (THVI) to describe the effects of those parameters on CBT of broilers under acute heat stress. The benefits of increased air velocity in broiler production have been well documented (Lott et al., 1998; Simmons et al., 2003; Dozier et al., 2005a, 2005b), but these studies only addressed the effects of air velocity within the context of air temperature, neglecting the effects of humidity, which should be incorporated for greater utility in managing the house environment. However, the interrelationship between air velocity, temperature, and humidity on production efficiency has not been defined.

Gates et al. (1995) developed a model to predict THI inside a broiler house, using the THI developed for layers by Zulovich and Deshazer (1990). Further, Timmons (1986) and Timmons and Gates (1988) illustrated the utility of predictive models in assessing the effects of different environmental conditions on productivity and profitability in poultry production. These models could also be updated to include current management practices and used to advise growers of the production implications of different management strategies.

Conclusion

As THI exceeds 20.8°C, heavy broilers show reduced performance and increased variability in performance metrics. Core body temperature of the birds rose significantly as THI increased. The observed reduction in performance and rise in body temperature illustrate the importance of air velocity and evaporative cooling for maintaining thermal comfort and production efficiency. The data suggest that a critical THI exists between 20°C and 26°C where additional cooling is necessary to prevent performance declines.

The variability observed in the data indicates the need for additional studies at different THI levels to improve prediction accuracy. However, the trends observed in the data show that THI has potential for implementation as a control parameter. With the near-universal adoption of microprocessor-based controls in modern broiler housing and adoption of robust relative humidity sensors over the past decade, using THI as a control parameter may allow poultry producers to effectively manage ventilation and cooling systems to maintain productivity, similar to the Livestock Weather Safety Index which warns cattle producers of weather conditions which may precipitate heat stress (NWSCR, 1976).

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