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Effects of carbon dioxide on turkey poult performance and behavior

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ABSTRACT Appropriate ventilation of poultry facilities is critical for achieving optimum performance. Ventilation promotes good air exchange to remove harmful gases, excessive heat, moisture, and particulate matter. In a turkey brooder barn, carbon dioxide (**CO_2**) may be present at higher levels during the winter due to reduced ventilation rates to maintain high temperatures. This higher CO_2 may negatively affect turkey poult performance. Therefore, the objective of this study was to evaluate the effects of subjecting tom turkey poults (commercial Large White Hybrid Converters) to different constant levels of atmospheric CO_2 on their growth performance and behavior. In three consecutive replicate trials, a total of 552 poults were weighed post-hatch and randomly placed in 3 environmental control chambers, with 60 (Trial 1) and 62 (Trials 2 and 3) poults housed per chamber. They were reared with standard temperature and humidity levels for 3 wks. The poults were exposed to 3 different fixed CO_2 concentrations of 2,000, 4,000, and 6,000 ppm throughout each trial. Following each trial (replicate), the CO_2 treatments were switched and assigned to a different chamber in order to expose each treatment to each chamber. At the end of each trial, all poults were sent to a local turkey producer to finish growout. For each trial, individual body weight and group feed intake were measured, and mortality and behavioral movement were recorded. Wk 3 and cumulative body weight gain of poults housed at 2,000 ppm CO_2 was greater ($P < 0.05$) than those exposed to 4,000 and 6,000 ppm CO_2. Feed intake and feed conversion were unaffected by the different CO_2 concentrations. No significant difference in poult mortality was found between treatments. In addition, no effect of CO_2 treatments was evident in the incidence of spontaneous turkey cardiomyopathy for turkeys processed at 19 wk of age. Poults housed at the lower CO_2 level (2,000 ppm) demonstrated reduced movement compared with those exposed to the 2 higher CO_2 concentrations.

Key words: air quality, behavior activity, carbon dioxide, poultry, turkey poult

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INTRODUCTION

Ventilation in poultry facilities is a crucial factor for optimum bird performance. Ventilation rates can affect growth, flock uniformity, feed consumption, and feed conversion of poultry during the brooding and growing phases. Poultry facilities may have compromised air exchange during the colder months of the year because of the desire to minimize heating costs by reducing ventilation. Proper ventilation promotes good air exchange, removes excessive heat, moisture, particulate matter, and harmful gases such as carbon dioxide (**CO_2**), carbon monoxide (**CO**), and ammonia (**NH_3**) produced by poultry, bedding, and heating systems (Kocaman et al., 2006; Corkery et al., 2013). When suboptimal conditions exist, oxygen (**O_2**) availability may be reduced and levels of CO, NH_3, and CO_2 increased (Yahav et al., 2011; Corkery et al., 2013; Zhao et al., 2015).

One of the most important gases produced in an animal facility is CO_2. The CO_2 balance inside the house can vary by many factors, such as the litter or manure handling conditions and type of heater used (Xin et al., 2009; Calvet et al., 2011). In addition to being a product of bird respiration, CO_2 is one of the breakdown products after degradation of uric acid found in poultry manure; production systems utilizing deep litter produce more CO_2 during microbial degradation (Jeppsson, 2000; Miles et al., 2006). Unvented conventional propane-fueled heaters produce water vapor, CO, and CO_2 inside the facility (Reece and Lott, 1980; Olanrewaju et al., 2008). In addition to ventilation rate, the number of birds, flock density, bird age, activity level, feed consumption, diet composition, and bird respiration all affect the CO_2 concentration levels inside poultry facilities (Pedersen et al., 2008; Calvet et al., 2011).

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Elevated CO_2 concentration can be harmful to turkeys, especially in the brooding period when poults start their development. Because CO_2 is heavier than air, it accumulates at the bird level and reduces O_2 concentration. The competition between CO_2 and O_2 for binding hemoglobin can cause hypoxia (Olanrewaju et al., 2008). Increased CO_2 concentration is purported to be one of the causes of round hearts in poultry (Owen et al., 1995; Wideman et al., 1999; Olanrewaju et al., 2008). Exposure of poults to excessive levels of CO_2 may also affect their metabolism. Donaldson et al. (1995) subjected tom poults to either ambient air (400 ppm CO_2), or 4,000 ppm CO_2 for 16 or 40 h post-hatch. The poults subjected to 4,000 ppm CO_2 were reported to be lethargic and had reduced whole-body glycogen and plasma thyroxine (**T4**) concentrations.

Changes in bird activity level can be used as one indicator of possible abnormalities and/or decreased productivity. Gerritzen et al. (2007) pointed out in their study that turkeys can sense atmospheric CO_2 concentration when it reaches 2.3% (23,000 ppm). They demonstrated this by injecting the gas into a test box to slowly increase CO_2 concentration. The birds' behavior changed with the increase in CO_2 levels. In this manner, behavior can be a useful tool for investigating animal comfort under specific conditions (Raj and Gregory, 1991).

Besides the negative consequences of high CO_2 that affect poultry development, CO_2 has also been used as a tracer gas for air quality monitoring and an indicator for minimum ventilation design (Feddes et al., 1984; Xin et al., 2009; Calvet et al., 2011). The International Commission of Agricultural and Biosystems Engineering (CIGR, 1984) established the maximum CO_2 concentration inside a facility at 3,000 ppm for general production and 2,500 ppm for poultry production. These values can be used to design appropriate minimum ventilation rates for maintaining indoor air quality. For example, with a real-time monitoring and control system, when CO_2 reaches 3,000 ppm, the fresh air ventilation should be increased.

Turkey brooder buildings can have suboptimal air quality during cold periods when ventilation is reduced to minimize heating costs (Noll et al., 1997). With insufficient building ventilation, oxygen availability is reduced under the brooder stoves, and harmful gas levels may also increase, which can cause the CO_2 level to reach 4,000 ppm (Corkery et al., 2013). A limited number of previous studies have examined the effects of increased CO_2 levels on turkey poults during the brooding phase, and these indicate that poor air quality might act as a stressor and contribute to early poult mortality (Donaldson et al., 1995; Frame et al., 1999).

Because increased CO_2 levels may negatively affect turkey poult growth and cause mortality, and also be used as a measure of air quality, it is of interest to determine whether elevated levels of atmospheric CO_2 would affect turkey poult performance. The objective of this study was to evaluate the influence of 3 constant CO_2 levels on tom turkey poult performance and behavior during the brooding phase.

MATERIALS AND METHODS

Experimental Design

All animal care procedures were approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC Protocol No. 16118).

This research was conducted using commercial tom turkey poults, randomly allocated to 3 environmentally controlled chambers. Each chamber measured 2.74 m long, 2.13 m wide, and 2.4 m high. A total of 552 tom turkey poults were used in this study, completed in 3 replicate trials. A total of 60 poults were placed in each chamber for Trial 1 (8.9 cm^2/poult), and 62 poults were placed in each chamber for Trials 2 and 3 (8.2 cm^2/poult). The experimental period was 3 wks (0 to 21 d of age). Light intensity of 86 lux was used and was supplied by 4 dimmable LED bulbs (5,000 K) controlled by an automatic timer. The Light:Dark (L:D) hourly schedule was 24L:0D, 23L:1D, 22L:2D, 21L:3D, 20L:4D, and 18L:6D for d 0, 1, 2, 3, 4, and 5 to 21, respectively, as outlined by Hybrid (2016).

All chambers followed a temperature control regime of 35–34°C, 33 to 32°C, 31°C, and 28°C for d 1 to 4, 5 to 7, 8 to 14, and 15 to 21, respectively (Hybrid, 2016). Each chamber was equipped with 2 electric heaters (Model 3VU31B, Dayton Electric Mfg, Lake Forest, IL, USA; Model CZ798, Howard Berger CO, Cranbury NJ, USA) and a ceiling-mounted air conditioner with chamber temperature controlled automatically (Model TC4-4SD, AP/Cumberland, Assumption IL, USA). The temperature and relative humidity at poult level in each chamber were recorded and monitored real-time (Model ZW-007, Onset Computer Corp, Bourne MA, USA). Fresh air ventilation at approximately 0.83 m^3/h per poult was provided via adjustable speed squirrel cage fans exhausting air to the outside of the larger building, and adjusted as needed for moisture control. Relative humidity was controlled within the range of 40 to 60% with an ultrasonic humidifier (Model HUL535W, Kaz USA, Inc., Marlborough, MA).

Tom poults were preselected for good quality and uniformity of body weight at the hatchery, transported to the laboratory where they were weighed individually, wing-banded for identification, and randomly placed in each chamber in order to have similar initial mean body weights between chambers (61 g/poult average). Prior to placing the poults, approximately 7 to 10 cm of medium-grade pine shavings were placed in each chamber. The bedding was mixed weekly as needed, and any wet or compacted litter was replaced with new pine shavings. All poults were provided feed and water ad libitum. In Trial 1, the poults were fed a commercial prestarter feed until d 17, and thereafter a starter feed until d 21. For Trials 2 and 3, poults

were fed a commercial prestarter feed for the entire 21-d period. In Trial 1, each chamber had 2 round feeders (3.2 cm/poult) and 2 bell-style waterers (2.7 cm/poult); modifications were made in Trials 2 and 3 to have one feeder and one waterer (2.2 cm/poult and 1.8 cm/poult, respectively), to more closely mimic commercial brooding conditions while maintaining welfare standards for space allocation. Egg flats and jug waterers were provided during the first 4 d to assist poult starting. Both arrangements exceeded the minimum recommendations of 1.9 cm/poult for feeder space and 1.27 cm/poult for waterer space (FASS, 2010). The number of poults placed was slightly adjusted to maintain similar net floor space density in each chamber (60 in Trial 1, and, 62 in Trials 2 and 3). Drinker water pH and oxidation-reduction potential (**ORP**) levels were monitored daily (Model HI 98121, Hanna Instruments Inc., Ann Arbor, USA) and adjusted using poultry water treatment (PWT water acidifier, Jones-Hamilton Co. Walbridge OH, USA) and bleach chlorine to obtain levels of 6.0 to 6.5 pH and 750 to 850 mV ORP.

A total of 3 constant atmospheric CO_2 concentrations (2,000, 4,000, or 6,000 ppm) were assigned randomly to the chambers. To maintain a 24×7 constant atmospheric CO_2 level inside each chamber, liquid CO_2 was vaporized, heated, and metered into each chamber and the flow rate was adjusted as needed as the poults grew. The concentration of CO_2 in each chamber was monitored and continuously recorded (Model GMP222, Vaisala Inc., Helsinki Finland; Model ZW-007, Onset Computer Corp, Bourne MA, USA) using instrumentation from portable air monitoring units (Gates et al., 2005). Following the completion of Trial 1, CO_2 levels were randomly reassigned to a different chamber for Trials 2 and 3, thereafter. At the end of each trial, all poults were sent to a local turkey producer to finish growout. The poults were all raised in 1 building; then at 19 wk of age they were euthanized and processed. Because all poults were individually wing-banded, an accurate i.d. was maintained to confirm which poults were raised in which CO_2 treatment chambers.

Mortality was recorded daily during the experimental period (0 to 21 d of age). No necropsy examination or collection of hearts was done during this period. In addition, no mortality records were maintained after the poults were sent to the local turkey producer. Poults were individually weighed at the end of each wk, on d 7, 14, and 21. Weekly body weight gain was calculated as the difference between body weight at the end of each week and weight at the week before, and cumulative weight was calculated as the difference between body weight at the end of 21-d period and the starting weight. Feed consumption was measured weekly, as the difference between feed provided and what was leftover in the feeders. Feed conversion was calculated weekly using the grams of feed consumed divided by grams of body weight gained.

At the end of the 19-wk growout phase, turkeys were randomly selected from the processing line from Trial 1 (N = 57) and Trial 2 (N = 101). Based on the possible evidence of spontaneous turkey cardiomyopathy (**STC**), a preselection of 33 and 31 hearts from these turkeys were sent to a testing laboratory (Best Veterinary Solutions) for cardiological evaluation. The hearts were evaluated for evidence of round heart and observations included measurements of shape, wall thickness, and general appearance.

Video Recording and Movement Analysis

For Trials 2 and 3, video images were recorded for 2 h during 3 periods of the day, 7 to 9 am (AM); 1 to 3 pm (NOON); 9 to 11 pm (PM), at 3, 4, 5, 10, 11, 12, 17, 18, and 19 d of age. A digital video camera (HDR-AS100V, SONY, Tokyo, Japan) was placed 1.8 m from the floor at the center of the environmental chamber, to record the entire floor area. The video recording had a resolution of 1,080 × 720 pixels and sampling rate of 29 frames per sec.

The algorithms used for movement analysis were written in Python (Python Software Foundation, 2016) open source programming language. The image processing was conducted using OpenCV 3.1 (Open Source Computer Vision) library functions. An algorithm adapted from Aydin et al. (2010) was applied in the recorded video to create a "movement index" (**MI**). This index expresses the amount of pixel intensity change, caused by the poults activity, in which the more the poults move the higher the index is.

The differentiation between frames was first obtained, then a binary movement image matrix was generated by testing whether pixel intensity change exceeded a threshold, as shown in Equation 1:

$$I_b(x,y,t) = \begin{cases} 1, if\ I(x,y,t+1) - I(x,y,t) > \tau \\ 0,\ otherwise \end{cases} \quad (1)$$

where $I\ (x,\ y,\ t)$ is the color (RGB) intensity of the image at the coordinate $(x,\ y)$ at time t. τ is a threshold to determinate whether the pixel will be assigned a 1 or 0, with 1 representing movement, and I_b is the resultant binary movement image matrix.

The MI at time t, $M_i(t)$, was calculated and normalized with the total area of the image, as shown in Equation 2.

$$M_i(t) = \frac{\sum I_b\ (x,y,t)}{WH} \times 100 \quad (2)$$

Where $M_i(t)$ is the MI (%) at time t, and $WH = (1{,}080 \times 720) = 777{,}600$ pixels. $\sum I_b\ (x,y,t)$is a sum of the binary image, over all coordinates $(x,\ y)$ at time t. An average MI for each min in the sample period was computed and used as a single observation in subsequent analysis.

Table 1. Performance of tom turkey poults subjected to 3 levels of CO_2.

	Treatments (ppm)[1]			*P*-value			
Age (wk)	2,000	4,000	6,000	Treatment	Trial	Contrast[2]	Pooled SEM
				Body weight gain (g/poult)			
1	153.0[a]	146.7[b]	150.8[a,b]	<0.002	<0.001	<0.010	17.2
2	282.6	273.2	276.8	0.162	<0.001	<0.010	47.3
3	454.7[a]	425.9[b]	423.3[b,c]	<0.001	<0.001	<0.010	72.2
Cumulative	891.7[a]	848.9[b]	851.2[b,c]	<0.001	<0.001	<0.001	109.6
				Feed intake (g/poult)			
1	200.7	194.0	198.9	0.406	<0.001	0.893	5.6
2	392.9	418.9	362.1	0.388	0.287	0.947	44.8
3	644.9	551.5	627.4	0.481	0.079	0.599	91.6
Cumulative	1,238.6	1,164.4	1,188.5	0.720	0.062	0.642	109.8
				Feed conversion (g feed:g gain)			
1	1.31	1.32	1.32	0.811	0.001	0.950	0.04
2	1.38	1.53	1.31	0.339	0.509	0.785	0.16
3	1.42	1.29	1.48	0.600	0.257	0.901	0.22
Cumulative	1.38	1.37	1.39	0.930	0.341	0.772	0.13

[a–c]Means within a row with different superscripts differ significantly ($P < 0.05$).
[1]Weekly means are an average of 3 replicate trials.
[2]Contrast results between control (2,000 ppm) vs. elevated CO_2 (4,000 and 6,000 ppm).
Abbreviation: SEM: Standard error of mean.

Statistical Analysis

Individual poult body weight gains were analyzed by analysis of variance (ANOVA) with fixed effects of treatment (3 CO_2 concentrations) and random effects of 3 trials (as blocks). Tukey means separation was used to determine significant differences between treatment means ($P < 0.05$). To further examine the treatment effects, a contrast between the control and elevated CO_2 treatments was performed for each Trial ($P < 0.05$). Weekly feed consumption and feed conversion by chamber were analyzed by ANOVA with fixed effects of treatment (3 CO_2 concentrations) and random effects of 3 trials (as blocks). The statistical analysis was performed using SAS (version 9.4, SAS Institute Inc., 2013).

The MI was analyzed by ANOVA with fixed effects of treatment (CO_2 concentrations), wk (1, 2, and 3) and time of the day (AM, PM, and NOON). The interactions between treatments and times of the day, for each week, were analyzed using SigmaPlot (Systat Software, Inc., 2009).

RESULTS

Mean weekly and cumulative body weight gain of turkey poults subjected to 3 different constant atmospheric CO_2 concentrations (2,000, 4,000, and 6,000 ppm) during 3 replicate trials are presented in Table 1. The targeted CO_2 levels were constantly maintained each day of the 21-d period within 500 ppm (0.05%) deviation. Poults subjected to 2,000 ppm CO_2 concentration gained more weight ($P < 0.05$) in wk 3, and cumulatively, as compared with poults subjected to the elevated CO_2 treatments. The poults subjected to 2,000 ppm CO_2 gained more weight ($P < 0.05$) than those in the 4,000 ppm CO_2 treatment during wk 1; however, no differences among treatments were found during wk 2. CO_2 treatment effect was significant for wk 1 ($P < 0.002$), wk 3 ($P < 0.001$), and wk 1 to 3 cumulative ($P < 0.001$).

The contrast test results for the cumulative period (wk 1 to 3), and weekly (wk 1, 2, and 3) body weight gain each showed a significant difference between the control treatment (2,000 ppm CO_2) vs. the 2 higher CO_2 concentrations (4,000 and 6,000 ppm CO_2). These results suggest that poults subjected to 4,000 and 6,000 ppm CO_2 had a suppressed body weight gain over the first 3 wks of brooding when compared with poults subjected to the 2,000 ppm CO_2 concentration.

Figure 1 shows the weekly body weights for the 3 treatments (mean and standard error), averaged over all 3 trials. The average body weight for poults exposed to 2,000 ppm was significantly greater ($P < 0.05$) than those in the 4,000 and 6,000 ppm, at 21 d of age. In addition, the average body weight of poults exposed to the 2,000 ppm CO_2 was higher ($P < 0.05$) than those in the 4,000 ppm CO_2 treatment at 7 and 14 d of age. These results follow the same pattern as the body weight gain with a suppression in weight at the 2 higher CO_2 levels.

Mean feed intake and feed conversion ratio of turkey poults are presented in Table 1. Other than a Trial effect noted in wk 1, feed intake and feed conversion did not show any differences between the CO_2 concentrations. This may be explained by the low number of degrees of freedom for chamber level evaluations (N = 9).

A total of 11 poults died during all trials. Four, 5, and 2 poults died in the 2,000, 4,000, and 6,000 ppm treatments, respectively; no significant mortality differences between treatments were found. A total of 6 hearts from the turkeys processed at 19 wk of age in Trials 1 and 2 showed evidence of STC, with an equal number of 2 hearts per treatment observed. Therefore, no treatment effect on STC was evident.

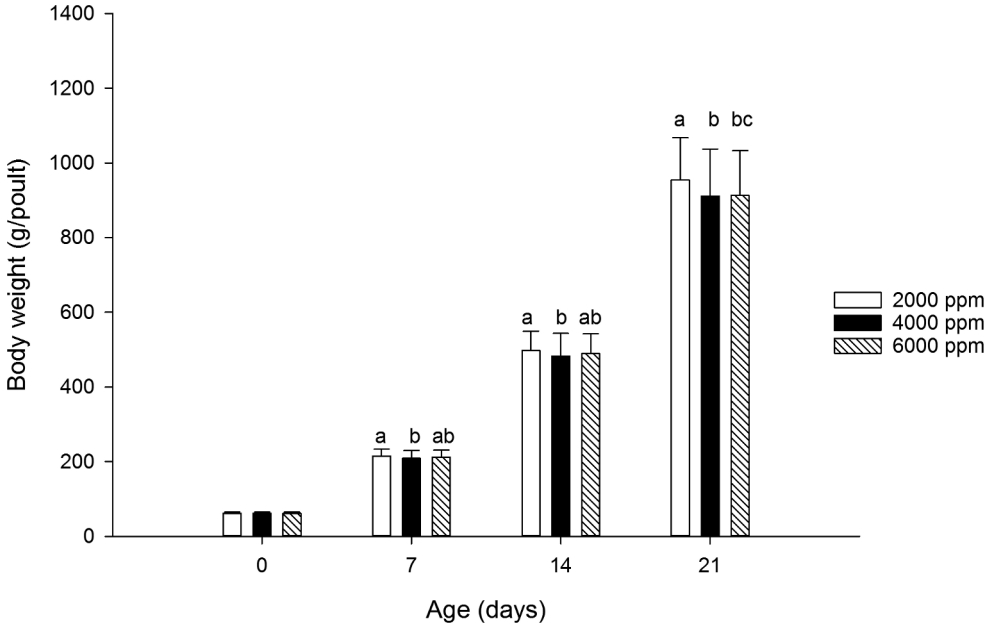

Figure 1. Mean body weight of tom poults subjected to 3 different CO_2 concentrations. Mean for each day is an average of 3 replicate trials. Means and standard error bars with different superscripts within each age differ significantly ($P < 0.05$).

Table 2. Mean movement index[1] (%) of tom turkey poults subjected to 3 different constant air CO_2 concentrations.

	CO_2 treatments (ppm)[2,3]				
Week	2,000	4,000	6,000	Pooled SEM	*P*-value
1	2.300	2.665	2.391	0.294	<0.060
2	6.660[b]	7.530[a]	7.639[a]	0.714	<0.001
3	8.667[c]	10.370[a]	9.791[b]	0.772	<0.001
P-value (Treatment)					<0.001
P-value (wk)					<0.001

[a–c]Means within a row with different superscripts differ significantly ($P < 0.05$).

[1]Mean movement index (MI) of poults inside each treatment for Trials 2 and 3. Movement index expresses the amount of pixel intensity change (%), caused by the poults activity, in which a higher index indicates greater poult movement.

[2]Weekly means are the average for Trials 2 and 3.

[3]Test of normality failed. Analysis of varience (ANOVA) performed on ranked median values between treatments used.

Abbreviation: SEM: Standard error of mean.

The weekly MI of turkey poults during Trials 2 and 3 are presented in Table 2. The MI significantly changed between the treatments ($P < 0.001$) during wk 2 and 3. Poults in the 2,000 ppm CO_2 treatment consistently had the lowest MI in wk 2 and 3 when compared with the other 2 treatments, meaning poults subjected to the 2,000 ppm CO_2 level had the lowest activity. For wk 3, the MI shows significant differences between all treatments ($P < 0.001$); poults in the 2,000 ppm treatment had the lowest MI, while those in the 4,000 ppm had the highest MI.

Table 3 shows the MI interactions between CO_2 level and different periods of the day during Trials 2 and 3. For wk 1, no difference was found between the CO_2 treatments for any of the periods of the day evaluated. For wk 2, no significant difference was found for the AM period; for the NOON and PM period, poults exposed to 2,000 ppm CO_2 exhibited lower MI ($P < 0.05$) vs. those in either 4,000 or 6,000 ppm CO_2 treatments. For wk 3, the MI for the 2 elevated CO_2 levels was consistently greater than those for 2,000 ppm, but not different from one another except for the PM period.

Table 3. Mean movement index[1] (%) of tom turkey poults subjected to CO_2 concentrations during 3 different periods of the day.

		Periods of the day[2,3]		
Week	Treatments (ppm)	AM	Noon	PM
1	2,000	2.088	2.707	2.105
	4,000	2.611	2.963	2.421
	6,000	2.477	2.422	2.274
	Pooled SEM	0.113	0.113	0.114
2	2,000	7.123	6.280[b]	6.579[b]
	4,000	7.039	7.350[a]	8.201[a]
	6,000	7.505	7.231[a]	8.181[a]
	Pooled SEM	0.113	0.138	0.113
3	2,000	8.185[b]	8.208[b]	9.608[c]
	4,000	9.448[a]	9.445[a]	12.219[a]
	6,000	9.519[a]	9.474[a]	10.381[b]
	Pooled SEM	0.113	0.113	0.113

[a–c]Means within a column per period of the day and week with different superscripts differ significantly ($P < 0.05$).

[1]Mean movement index (MI) of poults inside each treatment for Trials 2 and 3. Movement index expresses the amount of pixel intensity change (%), caused by the poults activity, in which a higher index indicates greater poult movement.

[2]Weekly means are the average for Trials 2 and 3.

[3]Test of normality failed. Analysis of varience (ANOVA) performed on ranked median values between treatments used.

Abbreviation: SEM: Standard error of mean.

DISCUSSION

The results for body weight (Figure 1) from this study tend to disagree with those presented by Reece

and Lott (1980), which showed that body weight at 28 d of age was not significantly different for male and female broilers raised with up to 6,000 ppm CO_2 concentration. In their study, which continuously exposed broilers to CO_2 for 28 d, only the 12,000 ppm CO_2 concentration treatment produced a significant reduction in body weight. However, their study showed that no significant differences in feed conversion occurred for broilers exposed to 1,000, 3,000, 6,000, or 12,000 ppm CO_2 at 4 wk of age. Thus, feed conversion results from the present study do agree with those found by Reece and Lott (1980). The different body weight results between the 2 studies can be due to comparing broilers with turkeys. In the present study, the body weight results for tom poults at 7, 14, and 21 d are similar to male broiler body weights reported for Ross 308 broilers (Aviagen, 2014). However, the response of tom poults to continuous high CO_2 levels may be different than it would be for broilers, possibly as a result of the physiological differences between turkeys and broilers. The necessity of updating the literature with modern poultry industry parameters was explained by Xin et al. (1998), as increasing rates of heat and moisture production in Nicholas tom turkeys from the literature were revealed.

Research by McGovern et al. (2001) concluded that CO_2 concentration had no effect on broiler final body weight. Their experiment started with 6,000 ppm CO_2, then reduced the CO_2 concentration to 2,500 ppm at the end of wk 6. In a more recent experiment, broilers were subjected to a control (350 ppm), 3,000, 6,000, and 9,000 ppm CO_2 concentrations (Olanrewaju et al., 2008). They found no significant difference between CO_2 treatments for body weight gain during periods of 1 to 28 and 1 to 42 d of age; however, for the period of 1 to 14 d of age, broilers showed differences in body weight gain between the control, 3,000, and 6,000 ppm treatments. They reported a significant difference in cumulative mortality in birds raised at 9,000 ppm. By contrast, our study found no difference in poult mortality between treatments, which is in agreement with the results of McGovern et al. (2001) and Olanrewaju et al. (2008) for broilers.

In this study, CO_2 concentrations did not affect the feed intake and feed conversion for all 3 wks. However, there were only 8 degrees of freedom for the analysis in Table 1. McGovern et al. (2001) also did not report a difference in these variables when comparing broiler performance in 2 different CO_2 concentrations of 2,500 and 6,000 ppm. The same result was found by Reece and Lott (1980) and Olanrewaju et al. (2008). It may be possible that the CO_2 concentrations were not high enough to affect these parameters.

Exposing birds to high CO_2 concentration is correlated with spontaneous turkey cardiomyopathy or round heart, given that CO_2 binds to hemoglobin and can lead to hypoxia and, consequently, induce right ventricular hypertrophy and ventricular failure (Julian et al., 1992; Frame et al., 1999; Mendes et al., 2013). McGovern et al. (2001) stated that no significant evidence was found for round hearts, but the size of the right ventricular area of the broiler hearts between the 6,000 and 2,500 ppm treatments was significantly different for the first experiment in their study. No difference was found for the second experiment in the same study. In our study, by contrast, no significant difference in the incidence of STC between treatments was found for turkey hearts examined at 19 wk of age. This may be due to the discontinued use of CO_2 after 21 d of age, and the concentrations of 4,000 and 6,000 ppm being insufficiently great enough to induce STC.

As shown in Tables 2 and 3, the poult activity increased with elevated CO_2, and with age. Broiler activity has been observed to increase in the afternoon periods, between 3 and 8 pm (Foshee et al., 1970). In this experiment, activity as measured by MI generally increased at 9 to 11 pm, for wk 2 and 3 for all the treatments, and for wk 2 for both 4,000 and 6,000 ppm treatments. The MI at NOON and PM periods was greater ($P < 0.05$) for the 2 higher CO_2 treatments at wk 2 and 3. In wk 3, all 3 periods had greater MI ($P < 0.05$) for elevated vs. control CO_2 levels, and for the PM period, all 3 CO_2 treatments were different, which corresponds with body weight gain.

High CO_2 concentration can cause unconsciousness by depressing the central nervous system of poultry. Reports from field observations relate high CO_2 concentrations to drowsiness and reduced activity in turkey poults, in contrast with the activity observed in this experiment. Donaldson et al. (1995) reported that exposure of day-old turkey poults to 0.4% (4,000 ppm) CO_2 in the air for 16 h, resulted in altered metabolism, reduced glycogen reserves, and elevated plasma T4. They concluded that this level of atmospheric CO_2 was considered to be a stressor. Their study did not, however, examine behavioral activity. In a study using laying hens, Raj and Gregory (1991) conducted 2 experiments where the hens were exposed to 5, 7.5, and 10% CO_2 for 4 d. They reported that the hens tried to avoid an area where feed was provided when the level of CO_2 rose above 5%. Even though their study used laying hens, we observed similar behavioral activity which indicated that turkey poults may try to avoid higher CO_2 concentrations as evidenced by increased movement. Given these points, the elevated CO_2 concentrations in this experiment (4,000 and 6,000 ppm) may not have been high enough to induce the poults to exhibit drowsiness, as seen in the field. However, these CO_2 levels were sufficient enough to affect the poults' performance and behavior, as can be seen in the MI, in which poult movement increased after wk 1 and all test periods in wk 3.

CONCLUSIONS

The results of this study suggest that continuously exposing tom turkey poults to constant CO_2 concentrations of up to 6,000 ppm was not a strong contributing factor to reduced turkey poult performance during the first 3 wks of brooding. However, poults exposed

to the 2 higher concentrations of CO_2 did have reduced cumulative and wk 3 body weight gain compared to the control CO_2 concentration. Also, the poults subjected to the 4,000 and 6,000 ppm had their behavioral patterns altered, showing more movement. This may indicate that the poults were trying to avoid their exposure to these higher levels of CO_2 by increasing their movement activity.

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