EFFECTIVENESS OF NOVEL METHODS TO REDUCE HEAT STRESS IN BROILERS: CHILLED AND CARBONATED DRINKING WATER

P. O. Okelo, L. E. Carr, P. C. Harrison, L. W. Douglass, V. E. Byrd, C. W. Wabeck, P. D. Schreuders, F. W. Wheaton, N. G. Zimmermann

ABSTRACT. *The broiler industry is seeking effective and economical methods to minimize production heat losses. Poultry exposed to heat stress pant and experience reduced blood carbon dioxide concentration, suggesting that supplementing birds with carbon dioxide would be beneficial. Chilled drinking water also has a potential to reduce heat stress. The present studies seek to determine the effectiveness of offering carbonated or reduced–temperature water to two broiler flocks raised to 42 days of age. Bird production performance data obtained from the two studies were combined since environmental temperatures during both studies were mild with little heat stress activity, except for a sudden increase in environmental temperatures on day 38 in the second study. There were no significant differences in live weight, cumulative mortality, and feed–to–gain ratio at harvest when data obtained from the two studies were combined. Birds provided chilled drinking water showed a 1.2 L/bird greater cumulative drinking water use than those provided tap water at ambient temperature. Ambient air temperatures were between 29°C and 37°C during the hottest periods in either study. Reduced–temperature carbonated drinking water had better retention of dissolved carbon dioxide, as indicated by significantly lower pH ($p < 0.001$, at $\alpha = 0.050$) when compared with ambient–temperature carbonated drinking water.*

Keywords. *Broilers, Carbonated water, Chilled water, Drinking water, Heat stress, High environmental temperatures, Mortality, Production heat losses.*

Environmental extremes have harmful effects on production and well being of all domestic animals, including chickens. Hot ambient temperatures, above the zone of neutrality, approximately 22°C for adult chickens and 32°C for day old chicks (Smith, 2000), typify the summer season in the Delmarva Peninsula of the eastern U.S. These conditions characteristically reduce feed intake and growth rates and negatively affect feed efficiency in growing broilers (May and Lott, 1992). Prolonged periods of elevated temperature stress increase the time to reach market weight and increase mortality (Xin et al., 1994). To reduce heat stress, the broiler industry has incorporated mixing fans and evaporative cooling, using cooling pads or low pressure misting equipment, into its temperature management systems. Increasing air circulation in the broiler house when outside atmospheric temperature rises above 29.5°C is ineffective, and misting increases humidity levels. The combination of high humidity and elevated temperatures creates an environment for the cultivation of bacteria and spread of disease (Rose, 1997).

Panting is one of the visible responses of poultry during exposure to heat above the thermoneutral range. This specialized form of respiration dissipates heat by evaporative cooling at the surfaces of the mouth and respiratory passageways. During periods of high environmental temperature, broilers increase their respiratory rate by panting to enhance evaporative cooling. However, increasing the respiratory rate also increases the rate of carbon dioxide loss from the lungs, resulting in a corresponding decrease in blood concentration of carbon dioxide (Siegel et al., 1974). This phenomenon suggests that supplementing birds with carbonated drinking water would be advantageous. Lowered concentrations of hydrogen ions cause a rise in blood plasma pH, a detrimental condition generally referred to as alkalosis. Bottje et al. (1983) and Bottje and Harrison (1985) obtained better growth rate and feed conversion using carbonated water when compared with tap water as the drinking water source for broilers exposed to heat stress.

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The authors are **Phares O. Okelo, ASAE Student Member,** Graduate Student, **Lewis E. Carr, ASAE Member Engineer,** Instructor, **Paul D. Schreuders, ASAE Member Engineer,** Assistant Professor, and **Fredrick W. Wheaton, ASAE Member Engineer,** Professor and Chair, Department of Biological Resources Engineering, University of Maryland, College Park, Maryland; **Larry W. Douglass,** Professor and Associate Chair, **Charles W. Wabeck,** Professor Emeritus, deceased, and **Nickolas G. Zimmermann,** Associate Professor, Department of Animal and Avian Sciences, University of Maryland, College Park, Maryland; **Veronica E. Byrd,** Research Assistant, Lower Eastern Shore Research and Education Center, University of Maryland, Princess Anne, Maryland; and **Paul C. Harrison,** Professor Emeritus, Department of Animal Sciences, University of Illinois, Urbana–Champaign, Illinois; **Corresponding author:** Lewis E. Carr, Department of Biological Resources Engineering, 1461 Animal Science/Agricultural Engineering Building, University of Maryland, College Park, MD 20742–2315; phone: 410–742–1178; fax: 301–314–9023; e–mail: lc5@umail.umd.edu.

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Objectives

The objectives of this research were to determine the effectiveness of providing chilled tap, chilled carbonated, ambient–temperature carbonated, and ambient–temperature tap drinking water in a hot environment on: (1) broiler performance based on weight gain, feed–to–gain ratio, mortality, and water consumption, and (2) deboned yield of parts based on ready–to–cook weights.

Materials and Methods

Facility Description

The research was conducted in the 18–chamber Poultry Environmental Research Facility at the University of Maryland, Lower Eastern Shore Research and Education Center, Princess Anne, Maryland. The research facility was of pole and panel construction with eighteen 6.1 × 6.1 m independent windowless chambers. The chambers were arranged nine to each side of the house, and the sides were separated by a 1.5–m wide hallway. Each chamber housed 500 straight run, mixed sex, commercially available broilers. All birds were fed a commercial broiler ration ad lib throughout the study. The commercial company that supplied the birds determined the feeding program. Twelve chambers were available for each study.

Each chamber had its own feed, water, and ventilation systems (fig. 1). Each chamber had two nipple drinker lines placed 1.2 m from the wall parallel to the diagonal of the chamber with nipples located 20.3 cm apart, for a total of 36 nipples per chamber. Drinking water was available at all times. A feed line was located midway between the two nipple drinker lines for each chamber. The feed line had a 70 kg feed bin, seven 30 cm diameter feed pans, and one control pan to operate the feed system. Feed was weighed and distributed to the feed bins in each chamber by an overhead auger system running the length of the nine chambers. A regulated control valve in each chamber allowed the feed to flow into the correct chamber feed bins. Continuous lighting was provided by 100 W incandescent lamps over the feed line and 25 W incandescent lamps in the other two corners of each chamber.

Each chamber was equipped with a 26.6 cm diameter centrifugal fan and a 42.5 cm direct–drive axial fan regulated by a thermostat set 5°C above the desired chamber temperature. All chambers shared a common data acquisition system (Model MRL–25/48–PD–RC–64_DS–96IDL–RD/Y, Esterline Angus Instrument Corp., Indianapolis, Ind.) that was interfaced with a data logger (Model CR7X, Campbell Scientific, Logan, Utah) to measure and record drinking water use and ambient air temperatures, respectively.

The amount of drinking water used in each chamber was measured using a volumetric measuring device tapped into the water distribution line. The water volume measuring device consisted of a cylindrical acrylic reservoir, short and long liquid level control electrodes (corresponding to the upper and lower liquid levels, respectively), a solenoid–operated valve, and a circuit board that regulated the opening and closing of the valve (fig. 2). A digital counter registered one count for each operation (opening and closing) of the valve. The volume of water between the two levels was determined by calibration.

Data were obtained from two flocks of commercial broilers (flock 1 and 2 = study 1 and 2, respectively), each raised to 42 days of age starting with 21–day–old birds. Flocks were raised consecutively in the same facility during the summer months, when high ambient temperature and heat stress usually occur.

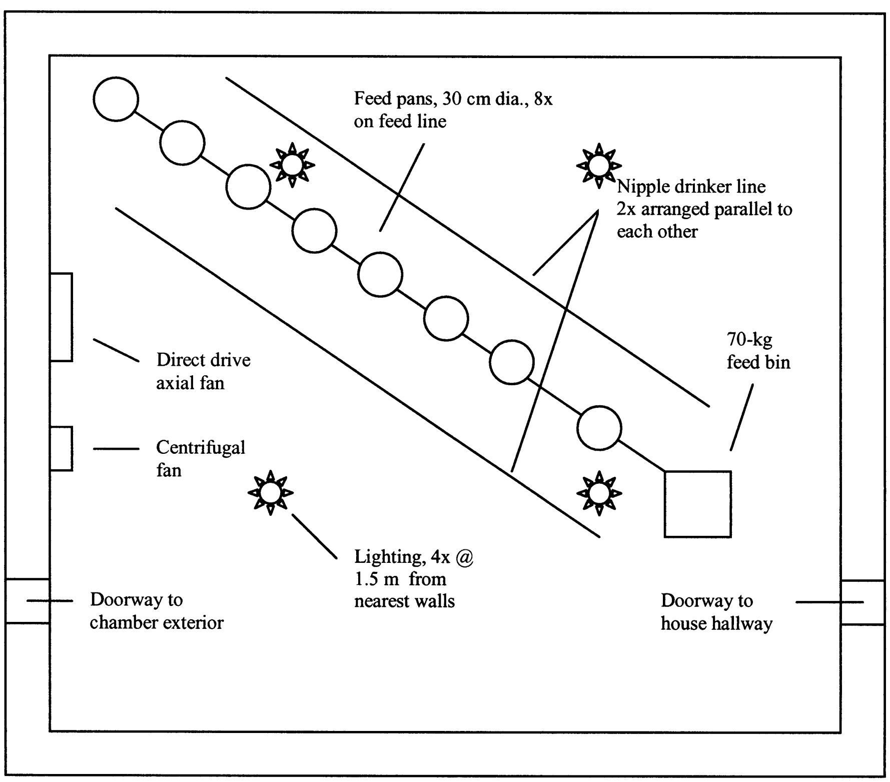

Figure 1. Layout of a 6.1 × 6.1 m chamber showing lighting, drinking water systems, and feed lines (not to scale). Light bulbs were 1.5 m to the nearest wall.

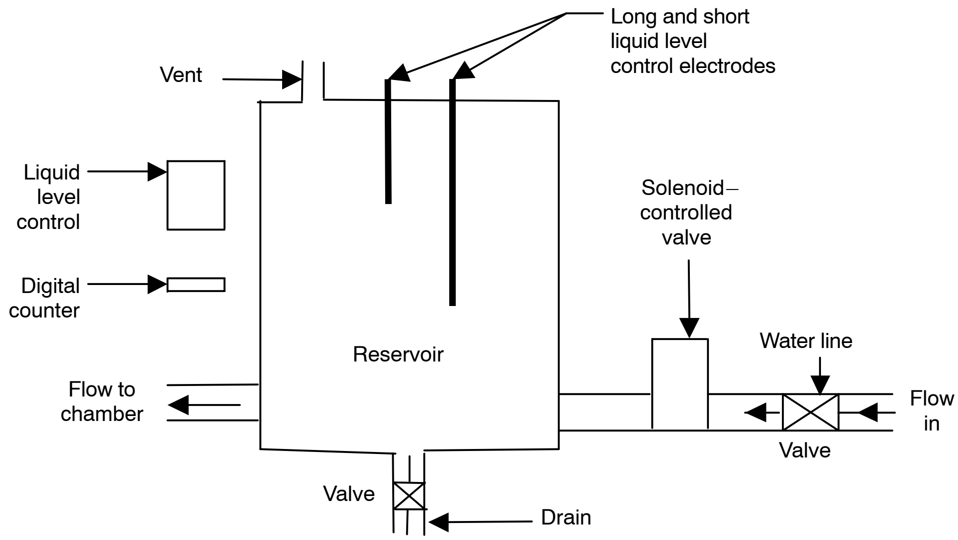

Figure 2. Schematic cross–section of the drinking water volume measuring device and its functional parts.

Carbonated and Chilled Drinking Water

All drinking water was supplied by the main municipal tap water line at ambient temperature. A carbonator consisting of a carbon–dioxide tank and a mixing tank connected together in a network with pressure–control valves and plumbing was used to provide chilled or ambient–temperature carbonated drinking water to the appropriate chambers (Park and Harrison, 1992). The carbonated water was delivered under pressure to the volume measuring devices whenever there was a demand in the chambers assigned to the carbonated drinking water treatment.

An Elkay water chiller (Model ER–2, Elkay Manufacturing Company, Oak Brook, Ill.) was installed in the main tap water and carbonated water lines, in the hallway above the chamber doorway, for each chamber assigned to the chilled drinking water treatments. The Val super cool watering system (Val Products, Inc., Lancaster, Pa.) was investigated but was not selected because of availability and cost. Water consumption was measured using the volume measuring device described earlier. Type T thermocouples (Omega Engineering, Inc., Stamford, Conn.) installed in each nipple drinker line and a data acquisition system (Model MRL–25/48–PD–RC–64_DS–96IDL–RD/Y, Esterline Angus Instrument Corp., Indianapolis, Ind.) were used to measure the temperature of drinking water in the chambers. Drinking water pH was monitored by taking 10 mL water samples from each nipple drinker line in a chamber and measuring water pH using pH strips (EM Science, Gibbstown, N.J.) every third day during the studies. Samples were extracted at the nipple farthest from the inlet end of each drinker line since this represented the worst case of dissolved carbon dioxide.

Performance Measurements

Live Weight: To determine the mean live weight in a chamber, three separate random representative samples of 25 birds, excluding inactive and frail birds, were weighed at harvest (6 weeks of age) using an electronic scale (Model FS300S, Sartorius North America, Inc., Edgewood, N.Y.), and the weight data were recorded and averaged.

Cumulative Mortality: The percentage mortality in a chamber was based on the 500 one–day–old chicks placed in each chamber on day 1. The number of dead birds in a chamber (mortality) was recorded daily. Percentage cumulative mortality was obtained by dividing the cumulative number of dead birds in a chamber at harvest by the number of birds placed in a chamber on day 1 and multiplying by 100.

Feed–to–Gain Ratio: Feed–to–gain ratio in a chamber was estimated at harvest, when birds were 6 weeks old. The cumulative amount of feed consumed at 6 weeks was divided by the average total weight of live birds (after accounting for the cumulative mortality until the current day). Average total weight of birds in a chamber was estimated by multiplying the mean weight of birds in a chamber by the number of live birds in the chamber at 6 weeks (harvest).

Cumulative Water Use: Cumulative drinking water use in a chamber (L/bird) was estimated by dividing the total water use in the chamber at harvest (6 weeks of age, measured using a volume measuring device) by the total number of live birds in a chamber at harvest.

Carcass Yield: Ten representative male broilers were selected from each chamber, slaughtered, and processed. Five carcasses were then selected randomly, cut into body parts, and the weight of body parts was recorded. Percentage carcass yield was computed by dividing the weight of a body part by the eviscerated weight of a bird and multiplying by 100.

Statistical Methods

Experimental and Treatment Design

Heat stress intervention treatments were identified as: chilled drinking water (C–H_2O), ambient–temperature carbonated drinking water (A–CO_2), chilled carbonated drinking water (C–CO_2), and ambient–temperature drinking water (A–H_2O), with ambient tap water as the drinking water control. The treatments were randomly assigned to twelve available chambers resulting in a complete randomized design with each treatment replicated three times. The treatments formed a 2×2 factorial treatment structure represented in table 1 with three replications.

Table 1. 2 × 2 factorial description of drinking water treatments. C–CO_2 = chilled carbonated water, C–H_2O = chilled tap water, A–CO_2 = ambient–temperature carbonated water, and A–H_2O = ambient–temperature tap water.

Carbonated Drinking Water	Chilled Drinking Water	
	No	Yes
No	A–H_2O	C–H_2O
Yes	A–CO_2	C–CO_2

Statistical Design

Data were analyzed using the linear mixed model procedure of SAS (version 8.1, SAS Institute, Inc., Cary, N.C.). The experiment was repeated (flock 1 and 2 = study 1 and 2, respectively), and each study was a completely randomized design with three replicate pens per treatment. The studies were analyzed separately, and when the results of the two studies were consistent, a combined analysis was completed and reported.

For the analysis of feed–to–gain ratio, bird weights, cumulative mortality, cumulative water use, and individual body parts, the fixed portion of the mixed model contained treatment effects, and the residual was defined as random for individual study analyses. For the analyses combining studies, the random portion of the model also included study and study × treatment interaction.

For litter moisture and drinking water pH, the data included repeated measurements over time. Therefore, in addition to the above, day and day × treatment were also included as fixed effects. The random portion of the model included pen within treatment and residual error. Repeated measures features of the mixed procedure were also used to fit the data, and goodness–of–fit statistics were used to identity a variance–covariance structure that adequately represented the repeated measures. The combined analysis included the same fixed effects, but the random sources of variation were study, pen within study and treatment, and the residual variance.

Results and Discussion

The summer of 1997 was a mild summer in the Delmarva Peninsula of the eastern U.S., with minimal heat stress activity. Ambient air temperature gradually rose above the thermoneutral range (22°C to 32°C for domestic chickens, depending on the age and weight of birds) (Smith, 2000) in both flocks. Figures 3 and 4 show ambient air and drinking water temperature variations with time on day 38 for flocks 1 and 2, respectively. Day 38 was one of the hottest days for flock 2. Days 39, 40, and 41 showed similar daily temperature variation for both flocks. Mean chamber data were analyzed separately for the two studies. Data obtained from the two studies were also combined and analyzed because environmental temperature conditions were similar during the studies except for a short period toward the end of the second study. Figure 5 shows mean daily ambient temperature variation in flocks 1 and 2 from 21 days of age until harvest. Although chamber ambient air temperatures gradually rose above the thermoneutral range of birds (approximately 25°C for birds 4 weeks and older) from day 33 until harvest in both flocks, flock 2 showed a sudden rise in temperature on day 38. Results of the combined analyses are presented in table 2.

Live Weight

Neither chilling (p = 0.432) nor carbonation (p = 0.611) of the drinking water had any significant effect on the live weight of birds in either study (table 2). Under the mild environmental conditions experienced by the birds during the studies (average ambient air temperature <30°C), the benefit of carbonation at chilled or ambient temperature in improving live weight of birds was not significant at $\alpha = 0.05$.

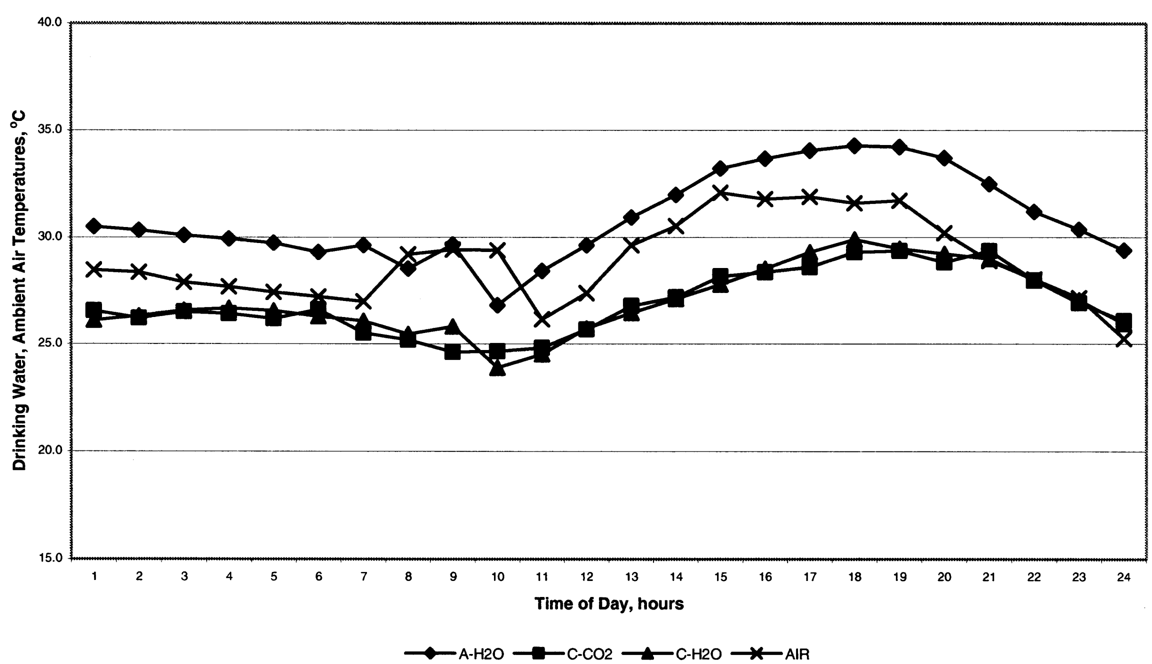

Figure 3. Variation of chamber air and drinking water temperatures, respectively, with time, on day 38 (one of the last four hottest days for flock 2) in flock 1. A–H_2O = ambient–temperature tap water, C–CO_2 = chilled carbonated water, C–H_2O = chilled tap water, and AIR = chamber air temperature.

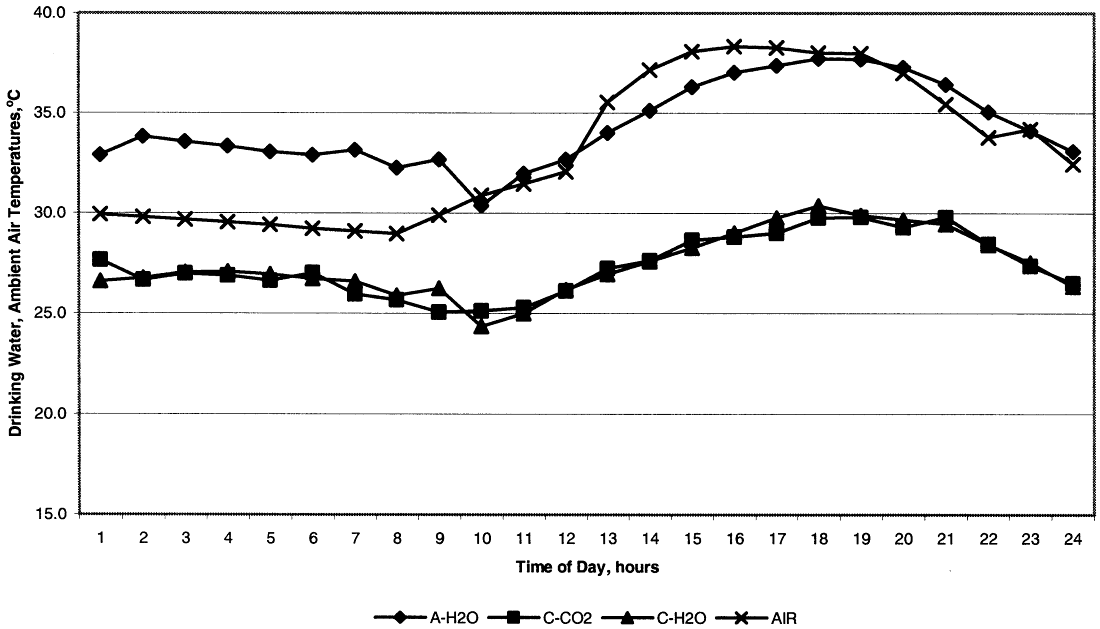

Figure 4. Variation of chamber air and drinking water temperatures, respectively, with time, on day 38 (the day that showed a sudden rise in ambient air temperature) in flock 2. A–H_2O = ambient–temperature tap water, C–CO_2 = chilled carbonated water, C–H_2O = chilled tap water, and AIR = chamber air temperature.

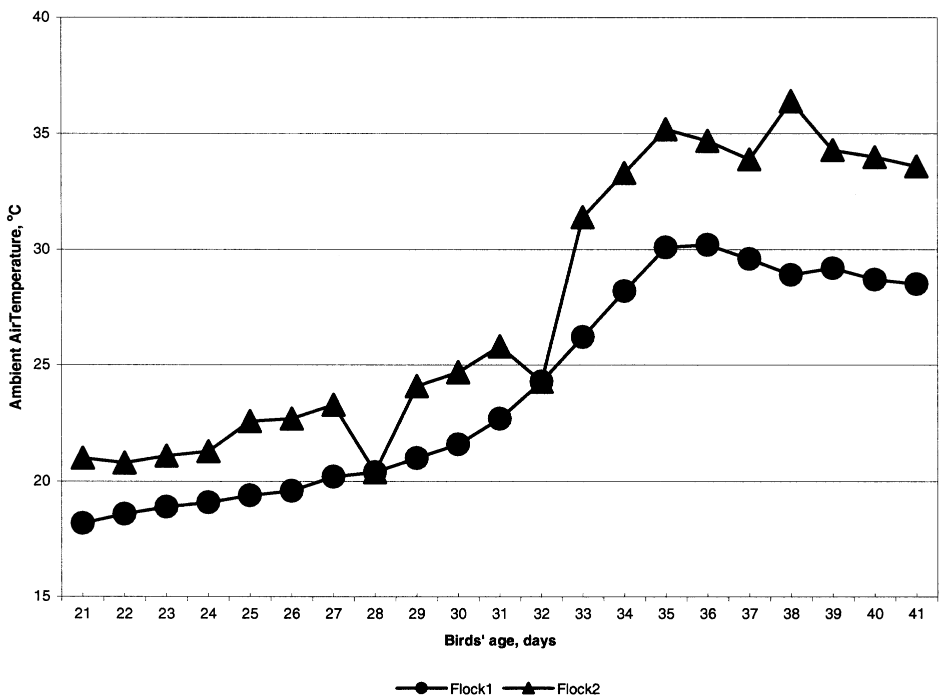

Figure 5. Daily mean ambient air temperature variation during heat stress intervention treatments (from 21 days of age until harvest).

Cumulative Mortality

When mean chamber mortality data were analyzed separately, neither chilled nor carbonated drinking water had any significant effects on cumulative mortality of birds in the first study. However, A–CO_2 and C–CO_2 had significantly lower cumulative mortality when compared with A–H_2O and C–H_2O, respectively, in the second study ($p = 0.011$ at $\alpha = 0.050$ – carbonation main effect). This result indicates that providing carbonated drinking water (ambient or chilled) to birds raised during elevated temperature conditions lowers their cumulative mortality, thus giving growers more birds at harvest. Lower cumulative mortality translates into greater profits through a greater number of birds and lower cumulative feed costs at harvest, respectively. Carbonation ($p = 0.157$, $\alpha = 0.050$) and chilling ($p = 0.919$, $\alpha = 0.050$) of drinking water had no significant effects on cumulative mortality of birds in the studies in the combined analysis (table 2). Greater variability of the means in the combined analysis, when compared with separate analyses of the mean

Table 2. Day 42 mean production performance, with standard errors and comparison test probabilities for planned comparisons. Each treatment was replicated three times. $C–CO_2$ = chilled carbonated water, $C–H_2O$ = chilled tap water, $A–CO_2$ = ambient–temperature carbonated water, and $A–H_2O$ = ambient–temperature tap water. SE indicates standard error of the mean.

	Variable							
	Weight (kg/bird)		Cumulative Mortality (%)		FGR (kg feed/kg bird)		Water Use (L/bird)	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE
$C–CO_2$	1.97	0.040	10.0	10.08	1.94	0.249	7.7	0.88
$C–H_2O$	2.02	0.021	15.9	10.08	2.16	0.248	9.1	0.88
$A–CO_2$	1.98	0.025	9.8	10.08	1.95	0.249	7.1	0.77
$A–H_2O$	1.96	0.040	16.9	10.08	2.11	0.249	7.4	0.77
Comparisons	Probability Values							
Cooling main effect	0.432		0.919		0.865		0.034	
Carbonation main effect	0.611		0.157		0.147		0.107	
Cooling × carbonation interaction	0.268		0.879		0.799		0.260	
$A–CO_2$ vs. $A–H_2O$	0.668		0.250		0.353		0.624	
$C–CO_2$ vs. $A–CO_2$	0.815		0.971		0.952		0.399	
$C–CO_2$ vs. $C–H_2O$	0.246		0.327		0.219		0.108	

cumulative mortality data, resulted in non–significant differences of the means in the combined analysis.

Feed–to–Gain Ratio

One observation for FGR in the second study was considered an outlier and was removed because it was 117% times greater than the treatment mean, thereby inflating the experimental error variance term in the analysis. Removal of the outlier resulted in an improvement of experimental error variance from 0.864 to 0.031. There were no significant chilled ($p = 0.225$ at $\alpha = 0.050$) or carbonated ($p = 0.327$ at $\alpha = 0.050$) drinking water effects, respectively, on FGR observed in the first study. There was no interaction between chilling and carbonation in either study ($p > 0.272$ at $\alpha = 0.050$). $A–CO_2$ and $C–CO_2$ had significantly lower FGR when compared with $A–H_2O$ and $C–H_2O$, respectively, in the second study ($p = 0.016$ at $\alpha = 0.050$ – carbonation main effect) when mean chamber FGR data were analyzed separately. This indicates that providing carbonated drinking water to broilers during high environmental temperatures (as experienced during the second study) would lower the feed–to–gain ratio and therefore result in lower cumulative feed costs to the growers. Neither chilling nor carbonation of drinking water had a significant effect on mean FGR when mean chamber FGR data for the two studies were combined ($p > 0.147$ at $\alpha = 0.050$); there was no interaction between the treatment factors ($p = 0.799$ at $\alpha = 0.050$).

Cumulative Water Use

One observation for cumulative water use in the second study was not included in the analysis of variance because it was 110% greater than the treatment mean and so was considered an outlier. Removing the outlier resulted in a decrease in experimental error variance from 9.0 to 0.8. When data were analyzed separately, there were no significant main effects of chilled or carbonated drinking water in either study ($p = 0.078$ at $\alpha = 0.050$); there were no significant interactions between the treatment factors ($p > 0.181$ at $\alpha = 0.050$). Chilling the drinking water significantly increased water consumption in $C–H_2O$ when compared with $A–H_2O$ ($p = 0.034$ at $\alpha = 0.050$) in the combined analysis (table 2). Further, carbonating the drinking water did not have any significant effect on drinking water use; there was no interaction between carbonation and chilling treatment factors.

Carcass Yield

Carcass yield data were analyzed both as separate studies as well as a combined study. Neither chilling nor carbonation of drinking water produced any significant effects on carcass yield of birds (table 3). There were no significant effects on body parts as a percentage of eviscerated weight. There was no interaction between the treatment factors. It was concluded that under the environmental temperatures that occurred during the present studies, neither chilling nor carbonation of drinking water had any effect on carcass yield. Chilling and carbonation, however, elevated production cost.

Drinking Water pH

Environmental heat stress activity occurred in the last four days of the second study. Drinking water pH data were therefore analyzed for that period in both studies. The drinking water pH of $A–CO_2$ was not significantly different from that of $A–H_2O$. Further, $C–CO_2$ had significantly lower pH when compared with $A–CO_2$ (table 4). Chilled carbonated drinking water retained its dissolved carbon dioxide more efficiently than ambient–temperature carbonated drinking water. This phenomenon may be explained by the fact that gases exhibit higher solubility in a solvent at lower temperatures than at higher temperatures (Johnson, 1999).

Production Cost of Birds

Chilling and carbonation of drinking water in order to alleviate heat stress in birds during periods of elevated ambient air temperatures did not show any significant effects on the production parameters considered in the combined studies. However, these heat stress interventions increased the cost of production of birds. Although the combined studies did not show any significant effects on feed–to–gain ratio, the high mortality that occurred just prior to harvest in the second study due to a sudden rise in environmental temperature resulted in higher mean feed–to–gain ratios in every treatment considered. Feed constitutes the largest portion of production cost, implying that large mortalities prior to harvest represent a considerable loss to the broiler production operation.

Table 3. Day 42 mean deboned yield as a percentage of shell weight and planned means comparison probabilities. Each treatment was replicated three times. C–CO_2 = chilled carbonated water, C–H_2O = chilled tap water, A–CO_2 = ambient–temperature carbonated water, and A–H_2O = ambient–temperature tap water. SE indicates standard error.

	Part									
	Breast		Thigh		Drum		Wings		Back	
Treatment	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
C–CO_2	35.5	0.78	18.6	0.37	15.6	0.21	13.7	0.44	17.1	0.72
C–H_2O	35.6	0.81	19.0	0.53	15.7	0.21	13.1	0.36	16.8	0.62
A–CO_2	36.5	0.50	19.1	0.49	15.1	0.48	13.0	0.49	16.4	0.40
A–H_2O	35.9	0.62	18.6	0.37	15.4	0.20	13.6	0.41	17.2	0.32
Comparisons	Probability Values (γ = 0.05)[a]									
Cooling main effect	0.354		0.795		0.239		0.961		0.785	
Carbonation main effect	0.683		0.664		0.495		0.997		0.647	
Cooling × carbonation interaction	0.579		0.484		0.637		0.197		0.371	
A–CO_2 vs. A–H_2O	0.417		0.478		0.518		0.398		0.174	
C–CO_2 vs. A–CO_2	0.290		0.727		0.358		0.397		0.456	
C–CO_2 vs. C–H_2O	0.928		0.844		0.825		0.350		0.801	

[a] Comparisons with p values less than 0.05 are significantly different from each other.

Table 4. Mean drinking water pH data during the period of heat stress in the second study and the corresponding period in the first study. Probabilities for planned comparisons are also presented. C–CO_2 = chilled carbonated water, C–H_2O = chilled tap water, A–CO_2 = ambient–temperature carbonated water, and A–H_2O = ambient–temperature tap water.

		Day	
		38	41
First Study			
Treatment	C–CO_2	6.0	6.0
	C–H_2O	8.0	8.1
	A–CO_2	7.9	7.9
	A–H_2O	8.1	8
Standard error of the mean		0.04	0.03
Planned Comparisons		Probability Values	
	A–H_2O vs. A–CO_2	< 0.001	1.000
	A–H_2O vs. C–CO_2	< 0.001	< 0.001
	CO_2 vs. C–CO_2	< 0.001	< 0.001
Second Study			
Treatment	C–CO_2	6.1	6.1
	C–H_2O	8.0	8.1
	A–CO_2	8.0	8.0
	A–H_2O	8.1	8.0
Standard error of the mean		0.12	0.12
Planned Comparisons		Probability Values	
	A–H_2O vs. A–CO_2	0.571	0.850
	A–H_2O vs. C–CO_2	< 0.001	< 0.001
	CO_2 vs. C–CO_2	< 0.001	< 0.001

Conclusions

The following conclusions were made:

- Environmental air temperatures were within the thermoneutral range of temperatures (22°C to 32°C depending on age and weight) of domesticated chickens for much of the production period in both studies, except for the last four days in the second study when temperatures rose above 32°C. Overall, heat stress activity as manifested in the production parameters, namely live weight, cumulative mortality, and feed–to–gain ratio, respectively, at harvest, showed no significant effects. Although chamber ambient air temperatures rose above the thermoneutral range of the birds in both studies for 22 % of the production period, the rise in temperature was gradual, except for day 38 in flock 2, and as such chilling and carbonation of drinking water did not produce significant benefits in live weight, cumulative mortality, feed–to–gain ratio, or carcass yield of birds in the combined studies. Chilling and carbonation of the drinking water during the production period increased the cost of production by an amount equivalent to the cost of maintenance and operation of the carbonator and Elkay chillers, respectively.
- Cumulative water use significantly increased in birds provided chilled tap water when compared with birds provided ambient–temperature tap water. Birds preferred chilled tap water during the environmental conditions of these studies.
- The drinking water carbonation system used in the present studies was effective in providing carbonated water at lower pH than tap water under chilled conditions.
- Although there were no significant treatment effects in the combined studies, carbonation of ambient–temperature and chilled drinking water resulted in lower cumulative mortality and lower feed–to–gain ratio, respectively, in the second study, in which high environmental temperatures were experienced close to harvest. The lower cumulative mortality and lower feed–to–gain ratios, respectively, represented lower production costs to the grower, as these would result in greater numbers of birds and lower cumulative feed usage at harvest. Feed cost represents the largest proportion of the operating expense in broiler production.

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