ENVIRONMENT AND HEALTH

Effect of Carbonated Water on Growth Performance of Cockerels Subjected to Constant and Cyclic Heat Stress Temperatures

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ABSTRACT Three growth trials were performed to determine the effect of carbonated water on growth performance of cockerels subjected to heat stress temperatures. In Trial 1, a 2 × 2 × 2 factorial design was used to test growth performance of Columbian crossbred cockerels between 8 and 11 weeks of age. The birds were subjected to either cyclic (day-night) heat stress (H) temperature (29 to 34 C) or cyclic (day-night) moderate (M) temperature (25 to 29 C), fed either a corn soy grower (G) diet or a 20% alfalfa diet (A), and provided with tap (TW) or carbonated (CW) drinking water. In Trial 2, a 2 × 4 × 2 factorial was used to access the effect of CW on growth performance of Hubbard cockerels between 4 and 7 weeks of age. Birds were grown in the M or H cyclic thermal environments with dietary treatments consisting of A, G, A plus 1% sodium bicarbonate (AB) and G plus 1% sodium bicarbonate (GB). In Trial 3, a 2 × 2 factorial was used to test the effect of CW on growth performance of Hubbard cockerels fed the G diet and subjected to either constant heat stress (33 C) or thermoneutral (25 C) temperatures. A 24-hr photoperiod was used in each experiment.

In all three trials, heat stress reduced ($P<.05$) average daily gain (ADG), feed intake, and feed efficiency (G/F). In Trial 1, ADG was greater ($P<.05$) in cockerels fed the G diet and provided CW than in those fed the G diet and provided TW or in those fed the A diet. In Trial 2, cockerels subjected to cyclic H and provided with CW had greater ($P<.05$) G/F than cockerels given TW. Feed intake was higher ($P<.05$) for birds given TW than if the cockerels were provided CW. In Trial 3, ADG for cockerels subjected to constant 33 C was greater ($P<.05$) for those given CW than if TW was provided. Feed intake was greater ($P<.05$) for cockerels at 25 C and given TW than in CW cockerels. When averaged over temperature effect, G/F was improved ($P<.05$) by CW treatment. The results indicate that CW improved G/F or ADG in heat-stressed cockerels.

(Key words: cockerels, growth, heat stress, carbonated water, sodium bicarbonate)

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INTRODUCTION

Hot ambient temperatures characteristically reduce feed intake and growth rate. At very high temperatures, feed efficiency can also be reduced (Dale and Fuller, 1980). Prolonged periods of elevated temperature increase mortality loss, especially after 4 weeks of age (McDougald and McQuistion, 1980), and accounts for substantial financial loss to the poultry industry.

In hot environments, thermal polypnea reduces blood carbon dioxide content, which produces an acid-base disturbance termed respiratory alkalosis (Linsley and Burger, 1964; Calder and Schmidt-Neilsen, 1966, 1967). Departures from normal acid-base chemistry reduce gains in chicks (Melliere and Forbes, 1966). Because optimal enzymatic and transport processes occur within a narrow range of hydrogen ion concentrations, deviations in acid-base balance may affect these processes and ultimately reduce productivity (Mongin, 1981). Therefore, the alkalotic condition during heat stress may contribute to lowered productivity characteristic of heat-stressed animals.

Odom (1982) demonstrated that providing carbonated drinking water improved shell quality and hen-day egg production in Single Comb White Leghorn (SCWL) hens exposed to heat stress. Because carbonated water improved blood acid-base balance during acute heat stress (Bottje and Harrison, 1985), the improved hen day egg production may be attributed to a partially corrected acid-base balance. Therefore, the objective of this study was to investigate the effect of carbonated water on growth performance of heat-stressed cockerels fed diets of high and low caloric densities with or without 1% sodium bicarbonate.

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TABLE 1. *Composition (%) of diets*

Ingredient	Standard regular grower (G)[1]	20% Alfalfa grower (A)
Corn	55.3	41.3
Oats	10.0	10.0
Soybean meal	24.5	20.5
Whey	2.0	2.0
Meat and bone meal	4.0	4.0
Alfalfa meal	2.0	20.0
Deflourinated phosphate	1.0	1.0
Limestone	.6	.6
Salt	.3	.3
Manganese sulfate	.05	.05
691 Vitamin premix	.25	.25

[1] GB and AB for Trial 2 were obtained by diluting the respective diets with 1% sodium bicarbonate.

MATERIALS AND METHODS

Three trials were designed to ascertain the effect of carbonated water on growth performance of cockerels exposed to elevated ambient temperature. Trials 1 and 2 were conducted in small houses (5 m^2) subject to daily temperature fluctuations. To simulate temperatures representative of hot nights and days, supplemental heat was added such that average midscotophase and midphotophase temperatures were 29 and 34 C, respectively, for birds subjected to cyclic hot (H) environmental temperature; birds assigned to cyclic moderate (M) temperature treatment were subjected to average midscotophase and midphotophase temperatures of 25 and 29 C, respectively. Relative humidity was not controlled and ranged from 60 to 70% in Trials 1 and 2. In Trial 3, birds were assigned to constant thermoneutral (25 ± .5 C) or constant heat stress (33 ± .5 C) treatments. Relative humidity was maintained between 50 and 55% in Trial 3.

Trial 1. In Trial 1, 7-week-old Columbian crossbred cockerels were randomly assigned in a 2 × 2 × 2 factorial design consisting of the following treatments: a) carbonated water (CW) *vs.* tap water (TW); b) standard grower diet (G) (2800 kcal/kg) *vs.* a 20% alfalfa diet (A) (2200 kcal/kg) (Table 1); c) cyclic M *vs.* cyclic H temperature treatment. The G and 20% A diet both contained approximately 20% crude protein. The A diet was used to determine the interaction of environmental temperature, CW, and a low energy density diet.

Trial 2. Sodium bicarbonate has been used in poultry diets with a positive effect on performance (Baker and Harrison, 1976); thus, it was decided to test the effect of CW in combination with bicarbonate diets.

In Trial 2, 3-week-old Hubbard cockerels were randomized in a 2 × 4 × 2 factorial experiment. Experimental protocol was the same as Trial 1 with the exception of two additional diets: grower + 1% sodium bicarbonate (GB) and 20% alfalfa + 1% sodium bicarbonate (AB) (Table 1).

In Trials 1 and 2, the birds were randomly assigned to diet, temperature, and water treatment and were housed 2 per cage in layer cages (20 × 40 cm floor space) equipped with rubberized flooring. The CW was obtained by bubbling carbon dioxide (CO_2) into a commercial medicator[2] connected to the drinking water line (Odom, 1982). The pH of TW and CW treatments was 7.7 ± .3 and 5.0 ± .2, respectively. Feed intake and gain were measured weekly.

Trial 3. The third trial was designed to evaluate the effect of CW on performance of cockerels subjected to constant heat stress and nonheat stress temperatures. Hubbard cockerels, 3 weeks old, were randomly assigned in a 2 × 2 factorial designed experiment. Experimental treatments consisted of a) constant thermoneutral temperature (25 C) *vs.* constant heat stress temperature (33 C); and b) TW *vs.* CW treatment.

Ninety-eight cockerels were housed 2 per cage within environmental control chambers regulated at either 25 ± .5 C or 33 ± .5 C constant temperatures. The CW treatment was provided as described in Trials 1 and 2. Feed intake and body weight measurements were made at 5-day intervals during the 25-day trial. At the end of the trial, left tibiae were removed from 5 cockerels per experimental treatment. The bones were ashed and analyzed for calcium by an atomic absorption spectrophotometer and phosphorus by colorimetry (Association of Official Agricultural Chemists, 1965). Analysis of data was obtained by SAS general linear model statistical package (Statistical Analytical Systems, 1982) on the

[2] Automedic II. Model AM 500 E, E. R. Squibb and Sons, Inc., Princeton, NJ.

Cyber-IBM System, University of Illinois. A 24-hr photoperiod was used in all three trials.

RESULTS

Growth performance in Trial 1 is summarized in Table 2. Cockerels fed diet G and provided CW had greater ($P<.05$) average daily gain (ADG) than cockerels fed G and given TW. As expected, reduced energy content in Diet A resulted in lower ($P<.05$) ADG and feed efficiency compared with Diet G. Heat-stressed cockerels at H cyclic temperature had lower ($P<.05$) feed intake ADG, (FI), and feed efficiency (G/F) than cockerels subjected to M cyclic temperatures.

The results of Trial 1 indicate that CW improved ADG. As Columbian cockerels characteristically grow slower, with lower feed efficiency, than commercial broilers, subsequent studies were conducted on Hubbard cockerels. In addition, because sodium bicarbonate may metabolically aggravate respiratory alkalosis associated with heat stress (Bottje and Harrison, 1985), 1% sodium bicarbonate was added to the G and A diets to test the effect of CW and dietary sodium bicarbonate on growth performance of cockerels during heat stress.

The results of growth Trial 2 are presented in Table 3. As in Trial 1, ADG, FI, and G/F were depressed by heat stress. Cockerels exposed to cyclic H temperatures gained equally well regardless of dietary treatment. However, in M cyclic temperatures, ADG was higher ($P<.05$) in birds fed G or GB diets when compared with those fed A or AB diets. Feed efficiency was lower ($P<.05$) in birds fed A and AB diets compared with those fed G or GB diets. Also, feed efficiency in G-fed cockerels tended ($P<.1$) to be higher in cockerels provided with CW compared with those given TW.

Figure 1 compares the effect of water treatment on overall Hubbard cockerel growth performance in Trial 2. Feed efficiency was greater ($P<.05$) and FI was lower ($P<.05$) in heat-stressed cockerels provided with CW compared with heat-stressed cockerels provided with TW.

Figure 2 summarizes the results obtained in the third growth trial. Birds subjected to 33 C and provided with CW had greater ($P<.05$) ADG than TW cockerels. Feed intake at 25 C was significantly greater ($P<.05$) for TW than for CW birds (Fig. 2a). Thus, feed efficiency was significantly greater ($P<.05$) in cockerels provided CW than in those given TW treatment (Fig. 2b).

Improved ADG in heat-stressed cockerels provided CW was achieved in the last 15 days of the trial (Fig. 3a). Feed efficiency in CW birds followed a similar trend, but the difference was not significant (Fig. 3b).

The concentration of tibia calcium (Ca) and phosphorus (P) obtained at the end of the third growth trial are presented in Table 4. Despite significantly lower ($P<.05$) % Ca in tibiae from heat-stressed cockerels given CW, no differences were observed in leg weakness, which would suggest that CW treatment had a deleterious effect on bone development.

DISCUSSION

Heat stress-induced depression of ADG and FI demonstrated in all three trials has been widely documented. In Trial 3, reduced feed efficiency of birds maintained at constant heat stress of 33 C is in agreement with results by Dale and Fuller (1980). Although feed efficiency was not affected by day-night temperature fluctuations of 25 to 35 C or 15 to 35 C imposed on growing turkeys (Hurwitz and Bengal, 1982) or 24 to 33 C imposed on broilers (Dale and Fuller, 1980), feed efficiency was reduced by the high narrow (day-night temperature range fluctuation) of 29 to 34 C in the present study. The elevated cyclic temperatures in Trials 1 and 2 might be more representative of prolonged periods of hot days and nights.

In general, birds fed lower energy A and AB diets exhibited increased ($P<.05$) FI and reduced ($P<.05$) feed efficiency and ADG. Appetite suppression at H cyclic temperatures restricted feed consumption such that cockerels fed the A and AB diets showed gains comparable to gains by cockerels fed the G or GB diets. However, gut fill may limit feed intake and growth by cockerels maintained at M cyclic temperatures and fed the A or AB diets.

Fuller and Mora (1973) demonstrated improved chick growth rate during heat stress when fat was added to the diet. The beneficial effect of high caloric density diets was realized when fat was included in the diet of birds subjected to cyclic heat stress temperatures of 23 to 33 C but not when constant 32 C was imposed (Dale and Fuller, 1980). Similarly, the elevated cyclic temperatures and dietary treatment effects on growth performance noted

TABLE 2. *Growth performance of Columbian crossbred cockerels exposed to cyclic heat stress (20 to 34 C) and moderate (25 to 29 C) temperatures from 8 to 11 weeks of age provided with carbonated water (CW) or tap water (TW)*[1]

Growth parameter	Temperature treatment	Dietary and water treatment				$\bar{X}$ Temperature
		Grower		20% Alfalfa		
		CW	TW	CW	TW	
Average daily gain, g/day	A) Cyclic hot	28 ± 1	25 ± 1	26 ± 1	26 ± 1	26 ± 1^{A}
	B) Cyclic moderate	37 ± 1^{a}	35 ± 1^{ab}	32 ± 1^{b}	34 ± 1^{ab}	34 ± 1
	$\bar{X}$ diet × water	32 ± 1^{a}	30 ± 1^{b}	29 ± 1^{b}	30 ± 1^{b}	
	$\bar{X}$ diet	31.1 ± .5		29.6 ± .5^{b}		
Feed intake, g/day	A) Cyclic hot	87 ± 2^{ab}	85 ± 2^{a}	92 ± 2^{b}	90 ± 2^{ab}	89 ± 2^{A}
	B) Cyclic moderate	112 ± 2	108 ± 2	111 ± 2	115 ± 3	112 ± 2
	$\bar{X}$ diet × water	100 ± 2^{ab}	96 ± 2^{a}	102 ± 12^{b}	103 ± 2^{b}	
	$\bar{X}$ diet	98 ± 1^{a}		102 ± 1^{b}		
Feed efficiency,[2] g/g[3]	A) Cyclic hot	.31	.31	.29	.29	.30
	B) Cyclic moderate	.32^{a}	.32^{a}	.29^{b}	.30^{ab}	.31
	$\bar{X}$ diet ± water	.32^{a}	.31^{a}	.28^{b}	.29^{b}	
	$\bar{X}$ diet	.31^{a}		.28^{b}		

^{a,b}Means in a row with different superscripts differ significantly (P<.05).

^{A}Means in a column and growth parameter differ significantly (P<.05).

[1] Each value (± SE) is the mean of three weekly replications with 6 birds per replication.

[2] Pooled standard error is .01.

[3] Gain/feed.

TABLE 3. *Growth performance of Hubbard cockerels exposed to cyclic heat stress (29 to 34 C) temperatures from 4 to 7 weeks of age provided with carbonated water (CW) or tap water (TW)*[1]

Growth parameter	Temperature treatment	Dietary and water treatment								$\bar{X}$ Temperature
		Grower		Grower + 1% $NaHCO_3$[2]		20% Alfalfa		20% Alfalfa + 1% $NaHCO_3$		
		CW	TW	CW	TW	CW	TW	CW	TW	
Average daily gain, g/day	A) Cyclic hot	32 ± 3	30 ± 2	33 ± 2	35 ± 2	32 ± 2	35 ± 2	32 ± 2	31 ± 2	33 ± 1^A
	B) Cyclic moderate	51 ± 2^a	51 ± 2^a	50 ± 2^a	50 ± 2^a	42 ± 2^b	46 ± 2^b	43 ± 2^b	43 ± 2^b	47 ± 1
	$\bar{X}$ diet × water	41 ± 2^{ab}	41 ± 1^{ab}	42 ± 1^a	43 ± 1^a	37 ± 2^b	40 ± 1^b	37 ± 1^b	37 ± 1^b	
	$\bar{X}$ diet	41 ± 1^{ab}		42 ± 1^a		39 ± 1^{bc}		37 ± 1^c		
Feed intake, g/day	A) Cyclic hot	83 ± 5^{ab}	82 ± 4^a	87 ± 4^{ab}	98 ± 3^b	93 ± 5^{ab}	95 ± 4^b	90 ± 3^{ab}	99 ± 3^b	90 ± 1^A
	B) Cyclic moderate	109 ± 4^a	113 ± 5^{ab}	110 ± 5^{ab}	111 ± 4^{ab}	111 ± 5^{ab}	126 ± 4^c	119 ± 4^{abc}	120 ± 9^{bc}	115 ± 1
	$\bar{X}$ diet × water	96 ± 5^c	98 ± 4^a	99 ± 5^a	105 ± 4^{ab}	102 ± 5^a	111 ± 4^{bc}	104 ± 4^{abc}	110 ± 4^b	
	$\bar{X}$ diet	94 ± 4^a		101 ± 3^{ab}		106 ± 3^{bc}		107 ± 3^c		
Feed efficiency[3] g/g	A) Cyclic hot	$.38^a$	$.34^{ab}$	$.37^a$	$.35^a$	$.34^{ab}$	$.35^a$	$.35^a$	$.31^b$	$.35^A$
	B) Cyclic moderate	$.45^a$	$.44^{ab}$	$.44^{ab}$	$.45^a$	$.37^{bc}$	$.36^{bc}$	$.35^c$	$.34^c$	.40
	$\bar{X}$ diet × water	$.41^a$	$.39^{ab}$	$.40^a$	$.39^{ab}$	$.36^b$	$.36^b$	$.35^b$	$.32^c$	
	$\bar{X}$ diet[4]	$.40^a$		$.40^a$		$.36^b$		$.34^b$		

a,b,c Means in a row with different superscripts differ significantly (P<.05).

A Means in a column and growth parameter differ significantly (P<.05).

[1] Each value (± SE) is the mean of three weekly replications with 4 birds per replication.

[2] Sodium bicarbonate.

[3] Gain/feed.

[4] Pooled standard error is .02.

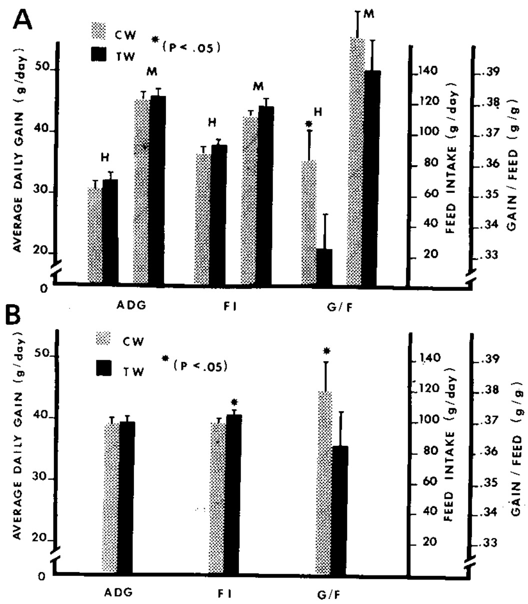

FIG. 1. A) Growth performance of Hubbard cockerels in Trial 2 provided with carbonated water (CW) and tap water (TW) and subjected to cyclic heat-stress (H) and cyclic moderate (M) temperatures. B) Growth performance of Hubbard cockerels in Trial 2 provided with CW and TW treatments.

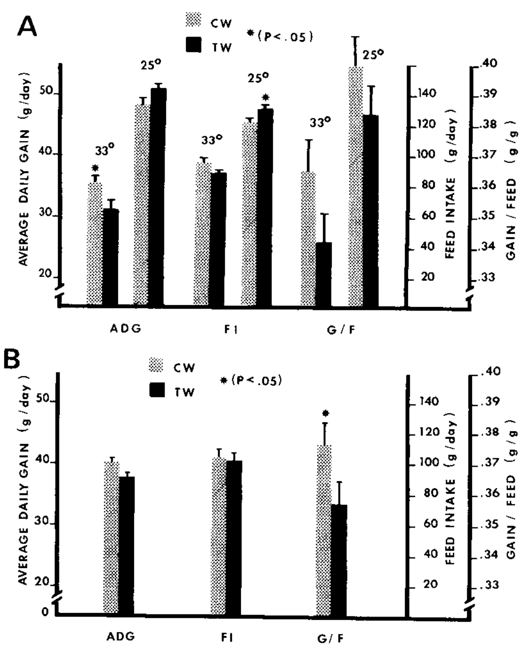

FIG. 2. A) Growth performance of Hubbard cockerels in Trial 3 provided with carbonated water (CW) or tap water (TW) and subjected to constant heat-stress (33 C) or nonheat-stress (25 C) temperature. B) Growth performance of the Hubbard cockerels in Trial 3 provided with CW and TW treatments.

in the present study confirm the effects of caloric density-temperature interaction on growth performance (Tables 2 and 3).

Although infusion of 2% bicarbonate solution into the crop of cockerels induced a metabolic alkalosis (Bottje and Harrison, 1984), addition of 1% sodium bicarbonate to Diet G in Trial 2 had no effect on growth performance of heat-stressed cockerels. Reduced feed efficiency was noted in heat-stressed cockerels fed the most alkaline diet (i.e., the AB diet) and provided with TW. These results support the hypothesis that CW may improve growth performance during heat stress by improving blood acid-base balance. One purpose of this study was to evaluate growth performance response of cockerels following replenishment of thermally depleted body CO_2. Average daily gain was improved in Trial 1 by CW treatment in birds fed diet G. The CW treatment also improved ADG when birds were subjected to constant heat stress temperature of 33 C. The

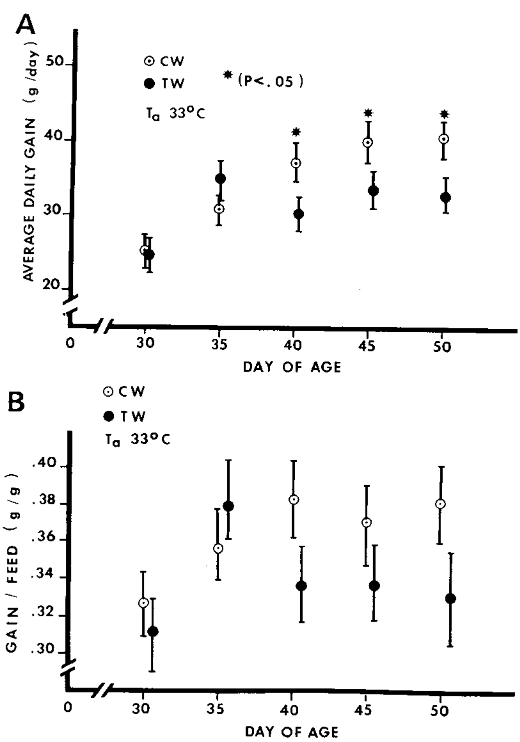

FIG. 3. A) Average daily gain at 5 day intervals of Hubbard cockerels in Trial 3 exposed to constant heat-stress (33 C) temperature. B) Feed efficiency (g gain/g feed intake) at 5-day intervals of Hubbard cockerels in Trial 3 exposed to constant heat-stress (33 C) temperature.

TABLE 4. *Percent bone calcium (Ca) and phosphorus (P) and Ca/P ratios of 50-day-old Hubbard cockerels exposed to constant thermoneutral (25 + .5 C) and heat stress (33 + .5 C) temperatures and given carbonated or tap water*[1]

	% Ca		% P		Ca/P	
	25 C	33 C	25 C	33 C	25 C	33 C
Tap water	38.4 ± .4	38.6* ± .4	20.0 ± .4	19.9 ± .4	1.93 ± .03	1.94 ± .03
Carbonated water	37.9 ± .4	37.3 ± .4	19.8 ± .4	19.5 ± .4	1.91 ± .03	1.91 ± .03

[1] Means are values of 5 birds ± standard error.

*Means in same column are different (P<.05).

CW improved feed efficiency in cockerels exposed to 29 to 34 C cyclic heat stress temperatures in Trial 2 and also improved overall feed efficiency of cockerels in Trial 3.

Dale and Fuller (1980) determined that 63% of heat stress induced growth depression could be explained by reduced feed intake the remainder must be attributed to other factors. In all three growth trials, respiration rate, although not measured, was observed to be considerably greater in heat-stressed birds. Hyperthermic polypnea has been shown to induce respiratory alkalosis in birds (Linsley and Burger, 1964; Calder and Schmidt-Neilsen, 1966, 1967; Odom, 1982; Bottje and Harrison, 1985). Melliere and Forbes (1966) demonstrated that dietary alteration of normal acid-base chemistry reduced gains in chicks. By altering CO_2 content in isolated liver preparations, Longmore *et al.* (1974) was able to alter carbohydrate and lipid metabolism and concluded that abnormal changes in acid-base balance can alter metabolism through changes in blood CO_2 content. Mongin (1981) indicated that deviation in blood acid-base balance may decrease metabolic efficiency resulting in reduced productivity. Thus, a portion of growth performance depression by heat stressed animals may be attributed to depressed blood CO_2 concentration during heat stress.

Carbonated water improved blood acid-base balance of cockerels exposed to an acute heat stress (Bottje and Harrison, 1985). Thus, the improvement in growth performance by CW treatment may have been due to a partial compensation of the acid-base imbalance of respiratory alkalosis. The improvement of feed efficiency in heat stressed birds given CW and fed the AB diet compared with those fed the AB diet and given TW lends impetus to this hypothesis.

Power failures caused a rapid rise in chamber temperatures on two occasions and resulted in severe mortality. However, mortality was less for birds provided with CW than for those given TW (25 *vs.* 50%, respectively). Burger (1980) suggested mortality could be minimized during periods of heat stress by raising ambient CO_2 in confinement houses to enable birds to continue to dissipate heat by evaporative cooling. It would appear that CW might also reduce mortality, but further studies are required to substantiate these observations.

Bone analysis from Trial 3 may have interesting ramifications for the layer industry. Harrison and Biellier (1969) proposed that respiratory alkalosis contributed to soft-shelled egg production characteristic of heat-stressed hens. Odom *et al.* (1982) demonstrated that blood ionized calcium decreased during an acute heat stress. Furthermore, CW treatment improved shell quality during chronic heat stress in SCWL hens (Odom *et al.*, 1985). In light of these findings, the results of the present study suggest that CW treatment may increase calcium mobilization from the bone which could be used for egg shell formation in heat-stressed hens.

The results of these preliminary studies indicate that CW may improve ADG or feed efficiency in heat-stressed cockerels. Tests on a much larger scale are needed before recommendations to industry can be made.

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REFERENCES

Association of Official Agricultural Chemists, 1965. Page 106 *in* Colorimetric procedure for phosphorus determination. Assoc. Offic. Agric. Chem., Washington, DC.

Baker, D. H., and P. C. Harrison, 1976. Sodium bicarbonate in the nutrition of swine and poultry. Natl. Feed Ingred. Assoc., West Des Moines, IA.

Bottje, W. G., and P. C. Harrison, 1985. The effect of tap water, carbonated water, sodium bicarbonate, and calcium chloride in cockerels exposed to heat stress. Poultry Sci. 64:107–113.

Burger, R. E., 1980. Respiratory gas exchange and control in the chicken. Poultry Sci. 59:2654–2665.

Calder, W. A., and K. Schmidt Neilsen, 1966. Evaporative cooling and respiratory alkalosis in the pigeon. Proc. Natl. Acad. Sci. 55:750–758.

Calder, W. A., and K. Schmidt Nielsen, 1967. Temperature regulation and evaporation in the pigeon and the roadrunner. Am. J. Physiol. 213:883–889.

Dale, N. M., and H. L. Fuller, 1979. Effects of diet composition on feed intake and growth of chicks under heat stress. I. Dietary fat levels. Poultry Sci. 58:1529–1534.

Dale, N. M., and H. L. Fuller, 1980. Effects of diet composition on feed intake and growth of chicks under heat stress. II. Constant *vs.* cycling temperatures. Poultry Sci. 59:1434–1441.

Fuller, H. L., and G. Mora, 1973. The effect of heat increment of the diet on feed intake and growth of chicks under heat stress. Pages 58–64 *in* Proc. Maryland Nutr. Conf.

Harrison, P. C., and H. V. Biellier, 1969. Physiological response of domestic fowl to abrupt changes of ambient air temperature. Poultry Sci. 48:1034–1045.

Hurwitz, S., and I. Bengal, 1982. Energy use and performance of young turkeys kept under various constant and cycling environmental temperatures. Poultry Sci. 61:1082–1086.

Linsley, J. G., and R. E. Burger, 1964. Respiratory and cardiovascular responses in the hyperthermic domestic cock. Poultry Sci. 43:291.

Longmore, W. J., A. M. Liang, and M. L. McDaniel, 1974. The regulation by carbon dioxide of carbohydrate and lipid metabolism in isolated perfused tissue. *In* Topics in Environmental Physiology and Medicine: Carbon Dioxide and Metabolic Regulation. A. Nahas and K. E. Schaefer ed. Springer-Verlag, New York, NY.

McDougald, L. R., and T. E. McQuistion, 1980. Mortality from heat stress influenced by anticoccidal drugs. Poultry Sci. 59:2421–2423.

Melliere, A. L., and R. M. Forbes, 1966. Effect of altering the dietary cation-anion ratio on food consumption and growth of young chicks. J. Nutr. 90:310–314.

Mongin, P., 1981. Recent advances in dietary cation-anion balance: applications in poultry. Proc. Nutr. Soc. 40:285–294.

Odom, T. W., 1982. The effects of high environmental temperature induced acid-base disturbance on the utilization of calcium by the domestic hen. Ph.D. diss., Univ. Illinois.

Odom, T. W., P. C. Harrison, and M. J. Darre, 1985. The effects of drinking carbonated water on the egg shell quality of Single Comb White Leghorn hens exposed to high environmental temperature. Poultry Sci. 64:594–596.

Odom, T. W., P. C. Harrison, B. Maine, and W. G. Bottje, 1982. Changes in blood acid-base balance and blood ionized calcium concentrations of SCWL hens during an acute heat stress. Poultry Sci. 61:1519. (Abstr.)

Statistical Analytical Systems, 1982. SAS Inst., Inc. Cary, NC.