Improving Eggshell Quality at High Temperatures with Dietary Sodium Bicarbonate

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ABSTRACT Two experiments were conducted that confirmed the hypothesis that a dietary bicarbonate supplement will improve eggshell quality in hens at high temperatures as long as feed is consumed during the period of eggshell formation. End-of-lay hens were maintained on continuous light at temperatures of 30 and 35 C. Individual egg weights and shell quality measures for each hen were calculated as a proportion of the initial values determined during an acclimatization period at 25 C. Improvements in shell breaking strength in both experiments were observed as a result of supplementing control diets with 1% sodium bicarbonate ($NaHCO_3$). This response to $NaHCO_3$ was not a reflection of a reduced rate of lay or egg mass output, as these were similar or inferior on the control diets. Similar feed intakes on the control and $NaHCO_3$ diets indicated that the response was not related to differences in calcium intakes. Supplements of zinc methionine and ascorbic acid proved to be inferior to $NaHCO_3$. Improvements in egg weight were associated with the introduction of continuous lighting.

(*Key words*: sodium bicarbonate, layer, high temperatures, eggshell quality, egg weight)

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INTRODUCTION

Both heat exposure *per se* and reduced appetite affect the laying performance and eggshell quality of hens exposed to high ambient temperatures. Whereas egg production and egg weight are influenced to a major extent by the reduction in feed consumption, eggshell quality is influenced primarily by high temperature (Sauveur and Picard, 1987). Efforts to improve laying performance at high temperatures have been relatively successful. Methods include the feeding of high nutrient density diets (de Andrade *et al*., 1977) and the use of self-selection feeding (Balnave and Murtisari Abdoellah, 1990). However, problems associated with eggshell quality have proved difficult to resolve.

The hyperventilation and respiratory alkalosis that occur when hens are housed at high temperatures are reflected in a loss of carbon dioxide from the blood and associated losses of bicarbonate from the blood and body fluids. This loss of carbon dioxide is accentuated by the need for blood bicarbonate to buffer the hydrogen ions produced during eggshell formation (Lorcher and Hodges, 1969; Makled and Charles, 1987). A reduced bicarbonate concentration in the lumen of the shell gland adversely affects eggshell quality (Frank and Burger, 1965; Balnave *et al*., 1989). Therefore, it is possible that, at high temperatures, hens have a nutritional requirement for bicarbonate, as has been suggested for broilers by Teeter *et al.* (1985) and Balnave and Gorman (1993). Lorcher and Hodges (1969) have shown that only a small amount of the bicarbonate required for eggshell formation in the shell gland is derived from the blood, a conclusion reached previously by Mongin and Lacassagne (1966) and subsequently confirmed by Cipera (1980).

Attempts to improve eggshell quality through supplementation of the diet or drinking water with sodium bicarbonate have been equivocal. Although positive responses have been observed by some (Frank and Burger, 1965; Howes, 1966; Makled and Charles, 1987) others have reported no benefits (Cox and Balloun, 1968; Pepper *et al*., 1968; Ernst *et al*., 1975; Hamilton, 1981; Obida *et al*., 1981; Hurwitz, 1987; Grizzle *et al*., 1992). Still others have reported benefits under specific conditions (Harms and Miles, 1980) or have obtained variable responses (Latif and Quisenberry, 1968). Howes (1966) appears to be the only one to have reported a beneficial response at high temperatures, although Ernst *et al.* (1975) reported that in hot weather hens receiving $NaHCO_3$ produced significantly fewer rough-shelled eggs.

The inconsistent responses to bicarbonate may reflect the fact that under a conventional daily 16 h photoperiod, the bicarbonate will not be consumed during the dark period, the time during which eggshell formation normally occurs. Therefore, the use of a continuous lighting regimen should allow the syn-

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chronization of eggshell formation with supplementary bicarbonate intake by the hen. However, the use of continuous lighting may also improve eggshell quality by allowing the hen access to dietary calcium during the period of eggshell formation (Hurwitz, 1987).

Makled and Charles (1987) reported that increasing the daily photoperiod from 16 to 24 h significantly improved egg weight and shell quality in laying hens, the improvements in shell quality being similar to those observed in the 16 h photoperiod when 0.5% sodium bicarbonate ($NaHCO_3$) was added to a diet containing ground limestone as the calcium source. Egg production and egg mass were unaffected by photoperiod or $NaHCO_3$. More recently, Grizzle *et al.* (1992) reported that supplying hens with an additional 2 h lighting period during the normal dark period resulted in an improvement in egg specific gravity but a supplement of 1% $NaHCO_3$ had no effect. Feed intake and egg production were unaffected by the photoperiod or the $NaHCO_3$. The use of a limited period of additional light during the normal dark period sometimes, but not always, gives rise to improvements in eggshell quality (Harms *et al.*, 1996). In this regard, Sauveur and Picard (1987) concluded that interruption of a normal night by a 1 or 2 h light period does not increase eggshell deposition.

Ascorbic acid is often used as a dietary supplement to offset the effects of heat in poultry, although the effect on eggshell quality is equivocal (Pardue and Thaxton, 1986). One situation in which ascorbic acid has proved beneficial has been in preventing the deterioration in eggshell quality induced by saline drinking water (Balnave and Zhang, 1992). This problem is associated with a reduced supply of bicarbonate ions to the lumen of the shell gland (Balnave *et al.*, 1989) caused by a reduced activity of carbonic anhydrase in the shell gland mucosa (Yoselewitz and Balnave, 1989). The studies on saline drinking water also identified certain zinc compounds, such as zinc methionine, as being beneficial to eggshell quality (Balnave and Zhang, 1993). This result is presumably due to the fact that zinc is an integral component of carbonic anhydrase and the improved zinc availability from these compounds may have increased the activity of this enzyme in the shell gland. Zinc proteinate supplementation of a standard layer diet has also been reported to improve eggshell quality (Sanford, 1966).

The present studies were conducted to determine whether supplying the hen with bicarbonate through dietary supplementation with sodium bicarbonate could improve the shell quality of eggs from hens maintained at high temperatures. The use of dietary supplements of ascorbic acid and zinc methionine were also examined. Continuous lighting was used to investigate the importance of allowing hens to consume the dietary supplements during the period of active eggshell formation.

MATERIALS AND METHODS

Hens (Tegel SuperBrown[1]) from the same University laying flock were used in both studies. They were 67 and 77 wk of age, respectively, at the commencement of Experiments 1 and 2. Mean rates of lay were 73 and 68%, respectively, at the beginning of Experiments 1 and 2. Hens were selected from a flock of 500 hens on the basis of rate of lay and eggshell breaking strength. All hens laying at least two eggs over a 3-d period just prior to the commencement of the individual studies were identified and the shell breaking strength of their eggs measured using a cantilever system (Balnave *et al.*, 1992). Hens laying eggs with shell breaking strengths above 25 N were selected for the individual studies. The hens were randomly assigned to the experimental treatments in temperature-controlled rooms. They were housed in individual cages and were given free access to feed and water at all times. Hens in each three adjacent cages were fed from the same feeder and feed intake comparisons were made using these data. All other comparisons involving egg output, including egg production, egg mass, egg weight, and eggshell quality were made using data from individual hens. Light was supplied from fluorescent tubes. Constant temperatures were used during each stage of the experiments.

The hens in Experiment 1 were given 2 wk to acclimatize to 25 C, with a 16 h daily photoperiod between 0430 and 2030 h, after transfer from the commercial shed. The temperature was then increased to 30 C and at the same time the daily photoperiod was increased to 24 h and the dietary treatments were introduced. The composition of the basal diets used in the studies are shown in Table 1. In Experiment 1, the diets fed were a basal diet (control) and the basal diet containing either 1% $NaHCO_3$, 0.05% zinc methionine, or 0.04% ascorbic acid. After 15 d at 30 C the temperature was increased to 35 C for 4 wk.

In Experiment 2, the same procedures were followed except that the daily photoperiod was maintained at 24 h throughout the experiment. The hens were given 4 wk to acclimate to 25 C and then were maintained for 4 wk at both 30 and 35 C. The dietary treatments were introduced when the temperature was increased from 25 to 30 C and consisted of a basal diet (control) and the basal diet containing either 1% $NaHCO_3$, 0.03% zinc methionine, or 0.02% ascorbic acid. Fresh diets were prepared every 2 wk to overcome any unlikely problems of stability with the ascorbic acid supplement, which was a stabilized silicon-coated product.[2]

Egg production and egg weight were measured daily and feed intake was measured over each of the individual temperature-treatment phases. During the final week of each temperature-treatment phase, eggs

[1]A. A. Tegel Pty. Limited, Camden, New South Wales 2570, Australia.

[2]Colborn Dawes Australia Pty. Limited, South Wagga, New South Wales 2650, Australia.

TABLE 1. Composition of diets

Ingredients and analyses	Experiment 1	Experiment 2
	(%)	
Wheat	41.40	72.80
Sorghum	25.00	. . .
Soybean oil	2.00	1.04
Soybean meal (45% CP)	20.30	7.67
Fish meal (65% CP)	. . .	7.61
Limestone (ground)	8.50	9.54
Dicalcium phosphate	1.60	0.96
Sodium chloride	0.20	0.27
L-lysine HCl	0.17	0.01
DL-methionine	0.33	. . .
Premix[1]	0.50	0.05
Calculated analysis		
ME, kcal/kg	2,750	2,790
CP, %	16.2	17.1
Available P, %	0.40	0.49
Na + K – Cl, mEq/kg	176	151
Determined analysis, %		
CP	16.4	17.3
Lysine	0.98	0.85
Methionine	0.60	0.37
TSAA	0.96	0.74
Calcium	3.43	4.12
Total P	0.57	0.75

[1]Provided per kilogram of diet: vitamin A (retinyl acetate), 6,000 IU; cholecalciferol, 1,200 IU; vitamin E (dl-α-tocopheryl acetate), 8 IU; menadione, 2 mg; riboflavin, 5 mg; calcium pantothenate, 6 mg; niacin, 15 mg; pyridoxine, 2 mg; folic acid, 0.5 mg; vitamin B_{12}, 5 μg; Mn, 50 mg; Zn, 50 mg; Fe, 30 mg; Cu, 2 mg; I, 2 mg; Co, 0.2 mg; ethoxyquin, 125 mg.

were collected and used for the determination of shell breaking strength, shell weight percentage, and shell thickness. Two eggs were taken from each hen in Experiment 1 and, in Experiment 2, two or three eggs were taken from each hen, depending on the rate of lay.

Twelve hens were allocated to each treatment in Experiment 1 and 24 hens to each treatment in Experiment 2. In Experiment 2, some hens moulted during the acclimatization period at 25 C and were removed from the experiment, leaving 22 hens on each treatment at the start of the high temperature exposure. Direct measurements of egg production and egg mass were made on individual hens but, because considerable variation existed in the initial shell quality measures from individual hens, the individual egg weights and shell quality measures for each hen were calculated as a proportion of the initial values determined during the final week of the acclimatization period at 25 C. Initial evaluation of the data was conducted using the Minitab General Linear Models procedure with the main factors being temperature and dietary supplements. Subsequently, main effects were tested by analysis of covariance controlling the effects of temperature on the

[3]BMDP IV, BMDP Statistical Software, Los Angeles, CA 90000.

TABLE 2. Absolute values for initial acclimatization (IA) and experimental (EM) measurements for egg weight and eggshell quality, Experiments (Exp.) 1 and 2

Treatment	Egg weight				Shell breaking strength				Shell weight				Shell thickness			
	Exp. 1		Exp. 2		Exp. 1		Exp. 2		Exp. 1		Exp. 2		Exp. 1		Exp. 2	
	IA	EM	IA	EM	IA	EM	IA	EM	IA	EM	IA	EM	IA	EM	IA	EM
	(g)				(N)				(%)				(μm)			
Temperature																
30 C	64.1	66.3	66.3	65.2	20.6	22.5	22.7	21.3	9.17	9.41	8.97	8.75	374	382	367	359
35 C	64.1	64.4	66.3	63.2	20.6	19.9	22.7	19.2	9.17	8.97	8.46	8.46	374	360	367	339
Diet																
Control	64.0	64.9	66.7	64.5	20.6	19.8	23.5	20.5	9.31	9.31	9.20	8.80	373	377	372	354
Sodium bicarbonate	62.9	67.4	66.6	64.5	20.4	22.6	21.8	20.8	9.24	9.19	8.83	8.69	374	370	366	352
Zinc methionine	63.6	65.3	64.9	62.8	20.6	20.6	22.8	19.8	9.06	8.92	8.85	8.30	375	360	360	337
Ascorbic acid	65.7	63.6	67.1	65.1	20.8	21.9	22.6	19.8	9.06	9.31	9.00	8.63	375	377	369	353

[1]Initial eggshell quality measurements on all diets were made on 12 and 22 replicates, respectively, in Experiments 1 and 2. Final measurements on the control, sodium bicarbonate, zinc methionine, and ascorbic acid treatments were made on 11, 11, 10, and 10 (Experiment 1), and 20, 19, 18, and 18 (Experiment 2) replicates, respectively.

TABLE 3. Main treatment effects on production responses, Experiments (Exp.) 1 and 2

Treatment	Feed per bird per d		Egg production		Egg mass per bird per d	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
	(g)		(%)		(g)	
Temperature						
30 C	100.9^{A}	93.0^{A}	71.6^{A} ± 1.78	66.9^{A} ± 1.57	46.6^{A} ± 1.10	43.1^{A} ± 1.00
35 C	78.8^{B} ± 2.09[1]	68.2^{B} ± 1.81[1]	58.8^{B} ± 1.78	53.8^{B} ± 1.64	37.6^{B} ± 1.10	34.4^{B} ± 1.04
Diet						
Control	89.6^{a}	80.8	68.1^{a} ± 2.40	57.8 ± 2.21	43.4^{a} ± 1.50	36.8^{bc} ± 1.42
Sodium bicarbonate	93.3^{a}	83.4	69.3^{a} ± 2.57	61.2 ± 2.29	46.1^{a} ± 1.54	41.3^{a} ± 1.46
Zinc methionine	96.1^{a}	81.2	61.5^{b} ± 2.46	63.9 ± 2.31	39.8^{b} ± 1.54	39.0^{ac} ± 1.43
Ascorbic acid	80.4^{b} ± 2.96[1]	77.0 ± 2.56[1]	61.8^{b} ± 2.63	58.6 ± 2.29	39.2^{b} ± 1.65	37.9^{c} ± 1.47

$^{a-c}$Means ± SEM within the same column and treatment with no common superscript differ significantly ($P < 0.05$).

^{A,B}Means ± SEM within the same column and treatment with no common superscript differ significantly ($P < 0.001$).

[1]Pooled SEM.

dietary responses, and analysis of covariance controlling the effects of diet on the temperature responses. Group differences were tested using an adjusted *t* test.[3]

RESULTS

The treatment egg weight and eggshell quality data were calculated as a proportion of the initial acclimatization values. However, the absolute measures are given in Table 2 for comparison.

The production responses at 30 and 35 C are shown in Table 3. No significant temperature by diet interactions were observed, so only the main effects are shown. In both experiments, feed intake, egg production, and egg mass were significantly reduced at 35 compared with 30 C. Mean overall reductions in feed intake were similar at 22 to 25 g/d, which gave reductions of 13% in rate of lay and 9 g egg mass/d. The dietary supplements significantly influenced egg mass output in both experiments. The egg mass output from hens receiving the $NaHCO_3$ was significantly greater than for hens receiving the zinc methionine and ascorbic acid in Experiment 1 and for control hens and hens receiving ascorbic acid in Experiment 2.

Egg weight and shell quality measurements at 30 and 35 C, relative to initial values at 25 C, are shown in Table 4. I n Experiment 1, increasing the temperature from 25 to 30 C at the same time as introducing continuous lighting gave a small increase in egg weight (value >1.0), and the reduction observed on exposure to 35 C approached significance. In Experiment 2, increasing the temperature from 25 to 30 C after hens had adjusted to continuous lighting gave a small decrease in egg weight (value < 1.0), which was significantly reduced by exposure to 35 C. In Experiment 1, diet had a significant effect, with the maximum egg weight response being obtained with the $NaHCO_3$ supplement. The supplements had no significant effect on the egg weight responses in Experiment 2. In Experiment 1, shell breaking strength, shell weight percentage, and shell thickness were all improved at 30 C but significant reductions occurred in all these measures when the temperature was increased to 35 C. In Experiment 2, increasing the temperature to 30 C gave small reductions in these shell measures, which were significantly reduced by exposure to 35 C. In both experiments, the shell breaking strength, but not shell weight percentage, or shell thickness, showed a response to dietary supplementation with the value from hens receiving $NaHCO_3$ being significantly improved compared to controls. The responses in shell breaking strength to the supplements of zinc methionine and ascorbic acid were not significantly different to controls.

DISCUSSION

In both studies, egg weight and eggshell quality were reduced at high ambient temperatures, in agreement with the results of previous studies (Sauveur and Picard, 1987). However, the present studies were designed to test the hypothesis that at high temperatures laying hens have a nutritional requirement for bicarbonate and that supplementation of diets with $NaHCO_3$ should improve eggshell quality as long as hens have access to feed during the period of eggshell formation. In these studies, the hens were maintained on a continuous lighting regimen, which allowed them to eat at any time of the day or night.

In both studies, shell breaking strength relative to controls was improved by dietary supplementation with 1% $NaHCO_3$. The improvement in shell breaking strength was greater in Experiment 1, in which the $NaHCO_3$ supplement was added to the diet at the same time as continuous lighting was introduced. The reduced response in Experiment 2 may be associated with the fact that the $NaHCO_3$ was given to these birds after the 4-wk continuous lighting acclimatization period at 25 C. These responses suggest that allowing hens continuous access to feed, irrespective of bicarbonate content, during the period of eggshell formation has advantages for eggshell quality at moderate temperatures.

This latter conclusion agrees with the results of Makled and Charles (1987), who found that improve-

ments in egg weight and eggshell quality occurred when the daily photoperiod for hens fed a diet containing ground limestone as the calcium source was increased from 16 to 24 h. In the present work the increase in egg weight observed as a result of increasing the temperature from 25 to 30 C in Experiment 1 did not occur in Experiment 2. Optimum egg weight at high temperatures is known to be dependent on dietary linoleic acid concentration (Balnave, 1987). The basal diet used in Experiment 2 contained less linoleic acid than that used in Experiment 1 (1.35 vs 1.8%). However, this is unlikely to have been a problem, as both diets satisfied linoleic acid requirements (National Research Council, 1994). Likewise, the dietary amino acid concentrations in both studies met recognized requirements at the feed intakes recorded (National Research Council, 1994), which suggests that the egg weight response was primarily a reflection of the lighting regimen, because in Experiment 2 the hens were acclimated to the continuous light prior to the increase in temperature to 30 C. In Experiment 2, the relative egg weights did not differ between dietary treatments so that the improvement in eggshell quality at the high temperatures resulting from feeding $NaHCO_3$ did not reflect differential changes in egg weight. Also, rate of lay and egg mass output were inferior on the control diet. Furthermore, the similar feed intakes noted with the control and $NaHCO_3$ treatments indicate that the beneficial responses in eggshell quality obtained with $NaHCO_3$ were not associated with an increased calcium intake.

The $NaHCO_3$-induced improvements in shell breaking strength (15 and 9% respectively in Experiments 1 and 2) occurred without any improvement in shell weight percentage and shell thickness in Experiment 1 and with only small (3 and 1%, respectively) improvements in Experiment 2. These results suggest that the $NaHCO_3$ improved shell ultrastructure rather than inducing additional eggshell formation (van Toledo *et al.*, 1982). Roberts and Brackpool (1994) have reported that in high temperature situations eggshell ultrastructure is modified in favor of shell strength even when shell thickness is reduced.

Ascorbic acid and zinc methionine were examined as possible dietary supplements for improving eggshell quality at high temperatures. Their potential value arises from the beneficial effect they exert on the shell quality of hens given saline drinking water, a treatment that reduces the supply of bicarbonate ions for eggshell formation through a reduced activity of carbonic anhydrase in the shell gland mucosa (Balnave *et al.*, 1989). The results show that these two supplements were inferior to $NaHCO_3$ and gave no benefit relative to controls. This contrasting response to that observed in the saline drinking water studies may reflect the fact that the carbonic anhydrase activity is increased in the shell gland of heat-stressed hens (Goto *et al.*, 1979).

As far as the authors are aware there is no evidence from previous studies that $NaHCO_3$ has an adverse

TABLE 4. Main treatment effects on egg measures in Experiments (Exp.) 1 and 2 as a proportion of initial values at 25 C

Treatment	Egg weight		Shell breaking strength		Percentage shell weight		Shell thickness	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
Temperature								
30 C	1.035 ± 0.0119	0.983^{X} ± 0.0030	1.092^{A} ± 0.0300	0.937^{A} ± 0.0174	1.026^{a} ± 0.0152	0.976^{x} ± 0.0062	1.021^{A} ± 0.0141	0.978^{X} ± 0.0065
35 C	1.005 ± 0.0123	0.953^{Y} ± 0.0037	0.967^{B} ± 0.0310	0.847^{B} ± 0.0190	0.978^{b} ± 0.0157	0.943^{y} ± 0.0067	0.962^{B} ± 0.0146	0.925^{Y} ± 0.0071
Diet								
Control	1.014^{b} ± 0.0166	0.967 ± 0.0050	0.962^{b} ± 0.0418	0.872^{b} ± 0.0250	1.000 ± 0.0213	0.957 ± 0.0090	1.011 ± 0.0197	0.953 ± 0.0093
Sodium bicarbonate	1.072^{ad} ± 0.0166	0.969 ± 0.0052	1.109^{a} ± 0.0418	0.952^{a} ± 0.0266	0.995 ± 0.0213	0.984 ± 0.0095	0.990 ± 0.0197	0.961 ± 0.0099
Zinc methionine	1.027^{bcd} ± 0.0173	0.967 ± 0.0051	0.998^{ab} ± 0.0438	0.868^{b} ± 0.0256	0.984 ± 0.0223	0.938 ± 0.0089	0.961 ± 0.0206	0.936 ± 0.0094
Ascorbic acid	0.968^{c} ± 0.0178	0.970 ± 0.0052	1.052^{ab} ± 0.0448	0.875^{b} ± 0.0259	1.028 ± 0.0228	0.959 ± 0.0092	1.004 ± 0.0211	0.957 ± 0.0098

$^{a-d}$Means ± SEM within the same column and treatment with no common superscript differ significantly ($P \leq 0.05$).
^{A,B}Means ± SEM within the same column and treatment with no common superscript differ significantly ($P < 0.01$).
^{X,Y}Means ± SEM within the same column and treatment with no common superscript differ significantly ($P < 0.001$).

impact on feed intake, egg production, or egg mass and this is confirmed in the present work. In fact, there were tendencies for improved performance in both of the present studies.

The results of these studies indicate that $NaHCO_3$ supplementation of diets for laying hens at high temperatures improves eggshell quality as long as hens have access to feed during the period of eggshell formation.

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