DIETARY SODIUM BICARBONATE, COCCIDIAL CHALLENGE, AND IONOPHORE COCCIDIOSTATS IN BROILER CHICKENS

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Primary Audience: Feed Manufacturers, Live Production Managers, Nutritionists, Processors, Researchers, Veterinarians

SUMMARY

Sodium bicarbonate, a widely available feed ingredient (27.1% sodium and 71.9% bicarbonate), was tested at levels of 0 to 0.4% in broiler chicken diets. Pen trials were conducted across several seasons at two locations. Built-up litter offered a "natural" exposure to coccidia in all of the studies. Some tests included inoculation with oocysts of three *Eimeria* species (*E. acervulina, E. maxima,* and *E. tenella*) via drinking water at 14 days of age.

Dietary sodium bicarbonate levels of 0.2 to 0.4% yielded significant improvements in body weight, feed efficiency, coccidial lesion scores, livability, carcass yield, breast yield, and occasionally, abdominal fat pad, although not all responses were found in all studies. A level of 0.1% sodium bicarbonate appeared ineffectual. The recommended range for continuous feeding of commercial broilers, day-old to market age, at all times of year is 0.2 to 0.3%. Given commercial broiler performance improvements (and concomitant reductions in feed expense per unit of live weight) similar in magnitude to those achieved in these experiments, and a typical price only 2 to 3 times that of salt in the United States, sodium bicarbonate exhibits a favorable benefit:cost ratio in broiler production.

Key words: Breast, broiler crosses, coccidial lesion scores, electrolytes, ionophore coccidiostats, livability, sodium bicarbonate, yield

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DESCRIPTION OF PROBLEM

Sodium bicarbonate ($NaHCO_3$), also called baking soda, contains 27.09% sodium, 71.91% bicarbonate, and no chloride. It is an FDA-approved (Code of Federal Regulations, Title 21, 582.1736) and "generally recognized as safe" feed ingredient. Mongin [1] characterized sodium bicarbonate as a "privileged" ingredient because it provides sodium, favorably affects blood pH, and supplies beneficial bicarbonate. Damron *et al.* [2] concluded that the sodium in sodium bicarbonate was equally bioavailable to that in salt for broiler chicks. Chloride levels can be reduced during feed formulation by partial replacement of salt with sodium bicarbonate on approximately a 1:1.5 ratio by weight. Baker *et al.* [3] concluded that sodium bicarbonate was needed at an optimal level of 1.5% in the Illinois crystalline amino acid standard reference diet for chicks.

In studying ways to counteract the growth-depressing action of high monensin, Jensen [4] reported that adding extra sodium (0.10%) from salt was without effect. In another experiment, either sodium bicarbonate (0.65%, most effective) or potassium carbonate (0.53%, second in effectiveness) significantly improved 4-wk body weights with high monensin (160 mg/kg), but salt (0.45%) did not.

Saylor and Fleet [5] at the University of Delaware evaluated the effectiveness of dietary sodium bicarbonate in providing various levels of sodium and potassium bicarbonate for reaching designated levels of potassium with either no coccidiostat, monensin, or lasalocid on 4-wk body weights of broiler chicks without a coccidial challenge in battery brooders. No statistical analysis was given. Without a coccidiostat, increasing sodium from 0.15% to 0.30 and 0.45% was without effect at 1.00% potassium. With monensin, 0.15 and 0.45% sodium treatments were equivalent at low or high potassium levels (0.50 or 1.00%) and 0.30% sodium not tested. With lasalocid, lower potassium diets performed better, and increasing dietary sodium to 0.30 and 0.45% improved growth over the 0.15% sodium level with both dietary potassium levels. In another test, the best 4-wk body weights were reached with 0.42% sodium, 0.55% potassium, and 0.27% chloride and either monensin or lasalocid.

Fox, Brown, and Southern [6] investigated 1.00% dietary sodium bicarbonate for broiler chicks with or without coccidial inoculation in battery brooders and found that the supplement improved gain and feed efficiency (no statistical analysis given). Gain was improved more in coccidiosis-infected chicks than in uninfected birds. No changes in the coccidiosis-induced liver copper increase or the duodenal pH decrease were observed with high dietary sodium bicarbonate.

Augustine [7] at the USDA Avian Coccidiosis Lab in Beltsville, MD, discovered in 1997 that sodium bicarbonate in the absence of a coccidiostat substantially increased the number of sporozoites in cross-sectional intestine (*E. acervulina*, +48%; *E. maxima*, +68%) following inoculation compared to inoculated control birds. With sodium bicarbonate plus monensin at 121 ppm, intestinal *E. acervulina* sporozoite counts were increased by 6.4% and *E. maxima* developmental stage counts were increased by 104%, compared to results for monensin alone. *E. acervulina* developmental stages were not reported. Whether the effect was due to sodium, bicarbonate, or a combination of the two was not determined. Enhancement of coccidial invasion has been associated with reduced coccidial lesions and improved performance by chicks, suggesting a possible stimulation or acceleration of immunity, thereby appearing to improve the efficacy of the ionophore coccidiostat. This effect is opposite that of betaine, also studied by Augustine [8], which helps cells resist the invasion of coccidia into intestinal epithelium and thereby enhances ionophore effectiveness.

Merrill [9] found from results of an unpublished survey of sodium bicarbonate use in broiler feeds in Western Europe that 0.2% was the most common level, in conjunction with 0.1% added salt, and the main purpose was to lower dietary chloride and reduce wet litter problems. Diets typically contained not more than 25% soybean meal and included fish meals, the latter having about 0.60% each of sodium and chloride. In diets without fish meal, it was typical to add up to 0.4% sodium bicarbonate.

Dose response studies with broiler chickens in pen trials under commercial-like conditions were needed to quantify the optimal range of sodium bicarbonate supplemen-

tation and the magnitude of the effects using different levels of coccidiosis challenge, bird crosses, and/or ionophore coccidiostats.

Materials and Methods

Trials were conducted from January 7, 1992 to January 28, 1994, during summer and winter at PARC Institute, Inc., Easton, MD, and at Colorado Quality Research (CQR), Inc., Fort Collins, CO. All birds were grown on built-up litter, with a covering of new litter, to expose birds to a "natural" coccidial challenge.

Peterson × Arbor Acres chicks were utilized in all studies. Ross × Ross chicks were also used in a factorial design for comparison with Peterson × Arbor Acres chicks in one test, 93-05B, in Maryland. All chicks were vaccinated for Marek's disease at the hatchery. At PARC Institute, chicks were also vaccinated for Newcastle disease and infectious bronchitis at the hatchery. In studies at CQR, chicks were given Newcastle disease and infectious bronchitis vaccinations at 5 days of age.

At PARC Institute each pen contained 88 or 90 chicks at placement (0.74 or 0.72 ft^2/bird). At CQR each pen held 70 chicks at placement (0.85 ft^2/bird). At both facilities, each chick that died during the first 7 days of a trial was replaced with a bird of the same sex from the same shipment. No chicks were replaced after noon on Day 7. At placement, chicks were considered 1 day of age. Mortality was recorded daily.

CQR feeds were based on corn, soy, meat and bone meal, and blended fat. For starter, grower, and finisher feeds, crude protein was approximately 23, 20, and 18%, respectively, with ME at about 1456 kcal/lb in all feeds. Sodium levels were estimated to be 0.20, 0.14, and 0.10% in starter, grower, and finisher feeds. Feeds were formulated to meet NRC [10] nutrient requirements, including those for sodium, but sodium levels were found after the test to be incorrect and were recalculated as above (grower sodium, 0.14%; finisher sodium, 0.10%; finisher chloride, 0.11%). Potassium was 0.89, 0.76, or 0.67%; chloride was 0.29, 0.20, or 0.11%. PARC Institute feeds were based on corn, soy, meat blend (58% crude protein), and blended fat. Crude protein was 23.7, 21.8, or 19.0%, with an ME of 1450, 1465, or 1475 kcal/lb. Calculated sodium percentages were 0.18, 0.16, or 0.15; potassium was 0.84, 0.73, or 0.65%; chloride was 0.27, 0.24, or 0.25%.

Starter feeds were crumbled and fed from 0 to 19 days at CQR and from 0 to 21 days of age at PARC Institute. Grower feeds were pelleted and fed from 19 to 40 days at CQR and from 21 to 41 days of age at PARC Institute. Finisher feeds were pelleted and fed from 40 or 41 days to 45 or 46 days of age in the different tests. In all cases, sodium bicarbonate was added "on top" of basal formulas (replacing an equal amount of corn) rather than being formulated in. For each 0.1% increment of sodium bicarbonate addition, dietary sodium was increased by 0.027%. Feed consumptions were determined by pens at the end of the starter and finisher feed phases. Feed conversions were calculated. Mortality-adjusted feed conversions have been reported in some cases, and these were determined by adding the weight of removed and dead birds to total live weight and dividing this into the total feed consumed.

At PARC Institute experiments in which chicks were given a coccidial challenge at 14 days of age, the inoculation consisted of oocysts of three *Eimeria* species: *E. acervulina*, about 100,000/bird; *E. maxima*, about 50,000/; and, *E. tenella*, about 10,000/bird. Standard operating procedure at PARC Institute to prevent cross-contamination of pens includes use of a solid 32" partition between pens to prevent litter crossover, assignment of different treatment pens to different caretakers, and disinfecting of boots between each pen. In both locations, coccidial lesion scores were taken at around 21 days of age (varied from 19 to 21 days) in these studies. At least four birds, two males and two females, in each pen were visually scored by looking at the upper small intestine, middle small intestine, lower small intestine, and ceca. These locations were totaled for a composite score per bird. The five-point system (0 to 4) was used for scoring, with categories as follows: 0 = normal, 1 = slight lesions, 2 = moderate lesions, 3 = severe lesions, and 4 = extremely severe lesions [11].

Slaughtering and processing, when done, used a sample of birds from each replicate pen, and the numbers sampled have been indicated in footnotes at the bottom of the tables of data. Dry or hot yield results for carcass or

breast were taken prior to chilling in ice water. Chilled or wet yield results for carcass or breast were taken after submersion in ice water. Breast yield was skinless, deboned meat. Abdominal fat pad was reported as either dry or chilled.

Completely randomized designs were used in Experiments 93-03 (five treatments) and 93-06 (four treatments). Experiment 93-05 involved two overlapping experiments having a common control treatment with factorial designs, and these two studies have been designated 93-05A and 93-05B. These involved two commercial broiler crosses and two bicarbonate levels. Data were subjected to Analysis of Variance (ANOVA) procedures to detect any significant effects. When effects were found to be significant for a parameter, means were separated by Tukey's Studentized Range (HSD) Test at CQR ($P < .05$) and by the Least Significant Difference (LSD) Procedure at PARC Institute ($P < .05$). Dose responses in studies 93-05A, and 93-06 (salinomycin 60 g/ton treatments) were subjected to linear regression analysis [12, 13].

Results and Discussion

EXPERIMENT 93-03

This May–July trial was conducted at CQR in pens with built-up litter. The 46-day body weight of male broilers fed salinomycin and 0.2% sodium bicarbonate was significantly improved compared to the control group (5.509 vs. 4.997 lb.) or the 0.1% sodium bicarbonate group (5.509 vs. 4.998 lb.) (Table 1). Feed efficiency during the trial was significantly better with 0.2% sodium bicarbonate (1.904 lb. feed/lb. body weight) than with the control feed, 0.1% sodium bicarbonate (1.952), or 0.4% sodium bicarbonate (1.944). Mortality-adjusted feed efficiency during the trial was significantly enhanced by 0.2% dietary sodium bicarbonate (1.836) compared to results of either the control (1.859), 0.1% sodium bicarbonate (1.861), or 0.4% sodium bicarbonate (1.861) treatments (Table 1).

Regression analysis revealed that dietary sodium bicarbonate from 0 to 0.4% in 0.1% increments caused a significant linear improvement in coccidial lesion scores ($P = .032$; $R^2 = .077$), and this dependent variable could be predicted by the linear regression equation: 1.75 + (% sodium bicarbonate × -1.146). A significant linear effect of sodium bicarbonate on 46-day body weight was observed ($P = .009$; $R^2 = .112$; increased), and body weight in lb. was predictable by the linear regression equation: 5.002 + (% sodium bicarbonate × 0.128).

It was observed from processing data that dry fat pad as a percentage of live weight was significantly reduced using 0.2% sodium bicarbonate in the diet (3.69%) compared to when no sodium bicarbonate was fed (4.08%) (Table 2). The 0.4% dietary sodium bicarbonate treatment gave an intermediate dry fat pad as a percentage of live weight (3.95%). Linear regression analyses were nonsignificant.

EXPERIMENT 93-05A

This June–July experiment was conducted at PARC Institute in built-up litter pens. Dietary treatments were applied, according to experimental design, with or without a coccidial inoculation via the drinking water at 14 days of age. Results have been presented in Tables 3A, 3B (regression analysis), and 4.

For uninoculated birds on built-up litter, coccidial lesion scores were significantly reduced by 0.2, 0.3, or 0.4% dietary sodium bicarbonate compared to results for control and 0.1% treatments (Table 3A). Using 0.4% dietary sodium bicarbonate yielded significantly heavier body weight than either control or 0.1% levels. Mortality-adjusted feed efficiency was significantly enhanced with 0.3 or 0.4% dietary sodium bicarbonate compared to control (0%) or 0.1% levels. Mortality percentage was significantly lower with 0.2% or 0.3% dietary sodium bicarbonate than with either control or 0.4% levels.

In uninoculated birds grown on built-up litter, significant trends (Table 3B) were found by linear regression with increasing dietary sodium bicarbonate for coccidial lesion scores ($P < .001$; $R^2 = .436$; decreased), body weight ($P = .014$; $R^2 = .148$; increased), and mortality-adjusted feed efficiency ($P < .001$; $R^2 = .363$; FCR decreased).

Coccidial-inoculated birds grown on built-up litter had significantly lower coccidial lesion scores using 0.2 to 0.4% dietary sodium bicarbonate than either control (0%) or 0.1% levels (Table 3A). Body weight was signifi-

TABLE 1. Effects of dietary sodium bicarbonate, 0 to 0.4%, on 19-day coccidial lesion scores and 46-day productive performance of male broiler chickens in built-up litter pens (Experiment 93-03; CQR; May 17–July 2, 1993)

DIETARY TREATMENTS[A]	COMPOSITE COCCIDIAL LESION SCORE[B]	BODY WEIGHT	FEED/BODY WEIGHT	MORTALITY	SDS[C] AND/OR ASCITES MORTALITY	MORTALITY-ADJUSTED FEED EFFICIENCY
		Lb	Lb/Lb	%	%	
Control	1.771[a]	4.997[b]	1.951[a]	6.183[a]	5.345[a]	1.859[a]
0.10% Na Bicarbonate	1.646[a]	4.998[b]	1.952[a]	6.213[a]	5.261[a]	1.861[a]
0.20% Na Bicarbonate	1.458[a]	5.059[a]	1.904[b]	4.659[a]	3.589[a]	1.836[b]
0.30% Na Bicarbonate	1.417[a]	5.025[ab]	1.928[ab]	5.952[a]	5.119[a]	1.840[b]
0.40% Na Bicarbonate	1.312[a]	5.047[ab]	1.944[a]	5.602[a]	4.643[a]	1.861[a]
LINEAR REGRESSION						
Probability	0.032	0.009	0.281	0.560	0.524	0.223
R^2	0.077	0.112	0.020	0.006	0.007	0.026
Prediction: Constant	+1.750	+5.002	+1.944	+6.004	+5.101	+1.855
NaBicarbonate % x	–1.146	+0.128	–0.038	–1.415	–1.547	–0.016

[A]Starter and grower feeds contained: salinomycin (50 g/ton) and Roxarsone (44 g/ton). Starter feeds also contained bacitracin MD (50 g/ton). There were 12 replicate pens of 70 birds each/treatment. Regression prediction equation coefficients in a column are to be combined to determine dependent variable.

[B]Average total coccidial lesion scores for upper, middle, and lower small intestine and ceca, using 0 to 4, least to most severe. Lesions were seen almost exclusively in the middle small intestine and ceca. Four birds were sampled per replicate pen.

[C]SDS is sudden death syndrome, also called "heart attacks" or "flipovers."

[a,b]Means in a column without a common superscript differ significantly by Tukey's Studentized Range (HSD) Test ($P < .05$).

TABLE 2. Effects of dietary sodium bicarbonate on 46-day litter moisture and processing yields of Peterson × Arbor Acres male broiler chickens in built-up litter pens (Experiment 93-03; CQR; May 17–July 2, 1993)

DIETARY TREATMENTS[A]	LITTER MOISTURE	DRY CARCASS	DRY FAT PAD	CHILLED CARCASS	BREAST
	%	% Live Weight			% Chilled Carcass Weight
Control	16.91[a]	65.36[a]	4.08[a]	67.23[a]	17.57[a]
0.10% Na Bicarbonate	16.50[a]	–	–	–	–
0.20% Na Bicarbonate	17.09[a]	65.65[a]	3.69[b]	67.45[a]	17.76[a]
0.30% Na Bicarbonate	17.38[a]	–	–	–	–
0.40% Na Bicarbonate	16.87[a]	65.42[a]	3.95[ab]	67.25[a]	17.88[a]

[A]Starter and grower feeds contained: salinomycin (50 g/ton) and Roxarsone (44 g/ton). Starter feeds also contained bacitracin MD (50 g/ton). Eight birds were sampled per replicate pen (96 per treatment) for processing. Breast meat is skinless and deboned.

[a,b]Means in a column without a common superscript differ significantly by Tukey's Studentized Range (HSD) Test ($P < .05$). Linear regression analyses were not significant (breast, % of chilled carcass weight, approaching significance at $P = .113$).

TABLE 3A. Effects of dietary sodium bicarbonate on 21-day coccidial lesion scores and 46-day productive performance of broiler chickens in built-up litter pens with or without coccidial inoculation via drinking water at 14 days old (Experiment 93-05A; PARC Institute; June 10–July 26, 1993)

DIETARY TREATMENTS[A]	COMPOSITE COCCIDIAL LESION SCORE[B]	BODY WEIGHT	MORTALITY-ADJUSTED FEED/BODY WEIGHT	MORTALITY
		Lb	Lb/Lb	%
UNINOCULATED				
Control	2.281[cd]	4.317[bc]	1.877[ef]	5.398[d]
0.10% Na Bicarbonate	2.469[bc]	4.345[bc]	1.854[de]	3.977[abcd]
0.20% Na Bicarbonate	1.344[fg]	4.354[abc]	1.832[abcd]	2.699[ab]
0.30% Na Bicarbonate	1.125[g]	4.386[ab]	1.816[a]	2.557[a]
0.40% Na Bicarbonate	1.219[fg]	4.420[a]	1.824[ab]	4.261[bcd]
COCCI INOCULATED				
Control	3.656[a]	4.235[d]	1.895[f]	5.114[cd]
0.10% Na Bicarbonate	2.625[b]	4.338[bc]	1.875[ef]	5.114[cd]
0.20% Na Bicarbonate	1.781[def]	4.368[ab]	1.844[bcd]	4.261[bcd]
0.30% Na Bicarbonate	2.000[cde]	4.290[cd]	1.850[cd]	3.693[abc]
0.40% Na Bicarbonate	1.438[def]	4.362[abc]	1.829[abc]	3.409[ab]
COMBINED AVERAGES				
Control	2.969[a]	4.276[b]	1.886[c]	5.256[b]
0.10% Na Bicarbonate	2.547[a]	4.341[a]	1.865[b]	4.545[b]
0.20% Na Bicarbonate	1.562[b]	4.361[a]	1.838[a]	3.480[a]
0.30% Na Bicarbonate	1.562[b]	4.338[a]	1.833[a]	3.409[a]
0.40% Na Bicarboante	1.328[b]	4.391[a]	1.826[a]	3.835[a]

[A]Starter feeds contained bacitracin MD at 50 g/ton. Salinomycin was added at 60 g/ton to all feeds. There were eight replicate pens with 88 birds each per treatment (44 males + 44 females).

[B]Average total coccidial lesion scores for upper, middle, and lower small intestine and ceca, using 0 to 4, least to most severe. Two males and two females were sampled per replicate pen for coccidial lesion scoring.

[a–g]Means in a column and group without a common superscript differ significantly by the Least Significant Difference Procedure ($P < .05$).

TABLE 3B. Linear regression analyses of experimental data used in Table 3A (Experiment 93-05A)

LINEAR REGRESSION ANALYSIS[A]	COMPOSITE COCCIDIAL LESION SCORE	BODY WEIGHT	MORTALITY-ADJUSTED FEED/ BODY WEIGHT	MORTALITY
		Lb	Lb/Lb	%
UNINOCULATED				
Probability	<0.001	0.014	<0.001	0.082
R^2	0.436	0.148	0.363	0.078
Prediction: Constant	+2.381	+4.315	+1.870	+4.517
NaBicarbonate % x	–3.469	0.247	–0.144	–3.693
COCCI INOCULATED				
Probability	<0.001	0.035	<0.001	0.006
R^2	0.537	0.112	0.392	0.184
Prediction: Constant	+3.312	+4.277	+1.890	+5.284
NaBicarbonate % x	–5.062	0.207	–0.159	–4.830
COMBINED AVERAGES				
Probability	<0.001	0.001	<0.001	0.002
R^2	0.430	0.121	0.354	0.117
Prediction: Constant	+2.847	+4.296	+1.880	+4.900
NaBicarbonate % x	–4.266	+0.227	–0.151	–4.261

[A]Prediction coefficients in a column should be combined to determine the dependent variable.

cantly improved by 0.2% added sodium bicarbonate compared to no supplementation. Mortality-adjusted feed efficiency was significantly better using 0.2 to 0.4% dietary sodium bicarbonate than at lower levels of supplementation. Mortality percentage was significantly lower using 0.4% dietary sodium bicarbonate than with either control or 0.1% levels.

Regression analysis of data from inoculated birds (Table 3B) indicated that significant linear trends occurred with increasing dietary sodium bicarbonate for coccidial lesion scores ($P < .001$; $R^2 = .537$; decreased), body weight ($P = .035$; $R^2 = .112$; increased), mortality-adjusted feed efficiency ($P < .001$; $R^2 = .392$; FCR decreased), and mortality ($P = .006$; $R^2 = .184$; decreased).

Combined averages for productive performance of uninoculated and inoculated birds are given in Table 3A. Levels of 0.2, 0.3, and 0.4% dietary sodium bicarbonate yielded significantly lower coccidial lesion scores than either control or 0.1% supplement treatments. All supplemented birds had significantly heavier body weight at 46 days of age than the control birds. Mortality-adjusted feed efficiency was significantly improved by dietary sodium bicarbonate levels from 0.2 to 0.4% compared to lower levels (*i.e.*, 0 or 0.1%), and the 0.1% level of supplementation gave a significantly better result than the control treatment. Mortality was significantly lower when broilers received either 0.2, 0.3, or 0.4% dietary sodium bicarbonate than when they got 0 or 0.1% levels.

Linear regression analysis for combined inoculation categories (Table 3B) indicated that increasing dietary sodium bicarbonate produced significant trends in coccidial lesion scores ($P < .001$; $R^2 = .430$; decreased), body weight ($P = .001$; $R^2 = .121$; increased), mortality-adjusted feed efficiency ($P < .001$; $R^2 = .354$; FCR decreased), and mortality ($P = .002$; $R^2 = .117$; decreased).

Processing results for Experiment 93-05A are listed in Table 4. Uninoculated birds fed 0.3% dietary sodium bicarbonate had significantly higher dry and chilled carcass yields as a percentage of live weight than control or 0.4% sodium bicarbonate birds. No significant linear trends were found by regression analysis for processing parameters. Although not shown in Table 4, it was found from polynomial regression analysis (x and x^2 as independent variables) that increasing dietary sodium bicarbonate gave a significant trend for chilled

TABLE 4. Effects of dietary sodium bicarbonate on 46-day breast yields and abdominal fat pads of broiler chickens in built-up litter pens with or without a coccidial inoculation via drinking water at 14 days old (Experiment 93-05A; PARC Institute; June 10–July 26, 1993)

DIETARY TREATMENTS[A]	DRY CARCASS	CHILLED CARCASS	DRY BREAST	CHILLED BREAST	DRY FAT PAD	CHILLED FAT PAD
	% Live Weight					
UNINOCULATED						
Control	65.34^{b}	67.23^{b}	13.99^{abc}	21.42^{abc}	3.94^{a}	6.03^{a}
0.10% Na Bicarbonate	65.92^{ab}	67.83^{ab}	14.38^{ab}	21.82^{ab}	3.71^{a}	5.63^{a}
0.20% Na Bicarbonate	65.88^{ab}	67.83^{ab}	14.44^{a}	21.92^{a}	3.71^{a}	5.62^{a}
0.30% Na Bicarbonate	66.21^{a}	68.07^{a}	14.16^{abc}	21.39^{abc}	3.86^{a}	5.82^{a}
0.40% Na Bicarbonate	65.47^{b}	67.35^{b}	13.93^{abc}	21.28^{abcd}	3.84^{a}	5.87^{a}
COCCI INOCULATED[B]						
Control	65.42^{b}	67.38^{ab}	13.35^{d}	20.41^{d}	3.86^{a}	5.91^{a}
0.10% Na Bicarbonate	65.91^{ab}	67.80^{ab}	13.73^{cd}	20.84^{cd}	3.78^{a}	5.73^{a}
0.20% Na Bicarbonate	65.96^{ab}	67.83^{ab}	13.72^{cd}	20.81^{cd}	3.91^{a}	5.93^{a}
0.30% Na Bicarbonate	65.54^{ab}	67.53^{ab}	13.60^{cd}	20.75^{cd}	3.81^{a}	5.81^{a}
0.40% Na Bicarbonate	66.03^{ab}	67.92^{ab}	13.85^{bcd}	20.98^{bcd}	3.79^{a}	5.75^{a}
COMBINED AVERAGES						
Control	65.38^{a}	67.31^{a}	13.67^{a}	20.92^{a}	3.90^{a}	5.97^{a}
0.10% Na Bicarbonate	65.92^{a}	67.82^{a}	14.06^{a}	21.33^{a}	3.74^{a}	5.68^{a}
0.20% Na Bicarbonate	65.92^{a}	67.83^{a}	14.08^{a}	21.37^{a}	3.81^{a}	5.78^{a}
0.30% Na Bicarbonate	65.87^{a}	67.80^{a}	13.88^{a}	21.07^{a}	3.83^{a}	5.82^{a}
0.40% Na Bicarbonate	65.75^{a}	67.63^{a}	13.89^{a}	21.13^{a}	3.82^{a}	5.81^{a}

[A]Starter feeds contained bacitracin MD at 50 g/ton. Salinomycin was added at 60 g/ton to all feeds. Ten males and ten females were sampled per replicate pen for processing.

[a–d]Means in a column and group without a common superscript differ significantly by the Least Significant Difference Procedure ($P < .05$). Linear regression analyses were not significant.

carcass as a percentage of live weight ($P = .051$; $R^2 = .148$; increased) and trends that approached significance for dry carcass as a % of live weight ($P = 0.064$; $R^2 = 0.138$; increased) and dry breast as a percentage of live weight ($P = .112$; $R^2 = .112$; increased).

Coccidial-inoculated birds (Table 4) fed dietary sodium bicarbonate had no significant treatment differences for processing results. No significant trends were detected for processing results of coccidial-inoculated broilers by linear regression analysis (Table 4). Similarly, combined inoculation category processing results (Table 4) gave no significant treatment differences or trends by regression analysis under conditions of this test. Although not shown in any table, dry carcass and chilled carcass data as a percentage of live weight approached trend significance by polynomial regression analysis ($P = .071$ and $P = .068$, respectively), and carcass yields tended to increase with increasing dietary sodium bicarbonate.

EXPERIMENT 93-05B

Tables 5 and 6 contain production and processing results for the June–July PARC Institute study in built-up litter pens using 0 or 0.20% dietary sodium bicarbonate (salinomycin at 60 g/ton) and Peterson × Arbor Acres or Ross × Ross chicks. Coccidial lesion scores, mortality-adjusted feed efficiency, and mortality were significantly improved by the supplement in both crosses. Body weight was increased significantly only in the Ross × Ross birds. Evaluation of main effects indicated that Ross × Ross broilers had significantly heavier body weight, but also had significantly higher coccidial lesion scores, possibly indicating less disease resistance or poorer immune status. Dietary sodium bicarbonate (0.2%) significantly re-

TABLE 5. Effects of dietary sodium bicarbonate on 21-day coccidial lesion scores and 46-day productive performance and processing yields of two commercial crosses of broiler chickens in built-up litter pens (Experiment 93-05B; PARC Institute; June 10–July 26, 1993)

DIETARY TREATMENTS[A]	COMPOSITE COCCIDIAL LESION SCORE[B]	BODY WEIGHT	MORTALITY-ADJUSTED FEED/BODY WEIGHT	MORTALITY
		Lb	Lb/Lb	%
PETERSON × ARBOR ACRES				
Control	2.281[b]	4.317[b]	1.877[bc]	5.398[b]
0.20% Na Bicarbonate	1.344[a]	4.354[b]	1.832[c]	2.699[a]
ROSS × ROSS				
Control	2.594[b]	4.362[b]	1.883[c]	4.545[b]
0.20% Na Bicarbonate	1.594[a]	4.471[a]	1.848[ab]	2.699[a]
MAIN EFFECTS				
Peterson × Arbor Acres	1.812[a]	4.335[a]	1.854[a]	4.048[a]
Ross × Ross	2.094[b]	4.416[b]	1.865[a]	3.622[a]
Control	2.437[b]	4.339[a]	1.880[a]	4.971[a]
0.20% Na Bicarbonate	1.469[a]	4.412[b]	1.840[b]	2.699[b]

[A]Starter feeds contained bacitracin MD at 50 g/ton. Starter and grower feeds contained salinomycin at 60 g/ton. There were eight replicate pens with 88 birds each per treatment (44 males + 44 females).

[B]Average total coccidial lesion scores for upper, middle, and lower small intestine and ceca, using 0 to 4, least to most severe. Two males and two females were sampled per replicate pen for coccidial lesion scoring.

[a–c]Means in a column and group without a common superscript differ significantly by the Least Significant Difference Procedure ($P < .05$).

TABLE 6. Effects of dietary sodium bicarbonate, 0 to 0.4%, with salinomycin at 60 g/ton on 46-day carcass and bresat yields and abdominal fat pad weights of two commercial crosses of male and female broiler chickens in built-up litter pens (Experiment 93-05B; PARC Institute; June 10–July 26, 1993)

DIETARY TREATMENTS[A]	DRY CARCASS	CHILLED CARCASS	DRY BREAST	CHILLED BREAST	DRY FAT PAD	CHILLED FAT PAD
	% Live Weight					
PETERSON × ARBOR ACRES						
Control	65.34[b]	67.23[b]	13.99[b]	21.42[b]	3.94[ab]	6.03[ab]
0.20% Na Bicarbonate	65.88[b]	67.83[a]	14.44[b]	21.92[b]	3.71[a]	5.62[b]
ROSS × ROSS						
Control	66.54[a]	68.01[a]	16.61[a]	24.96[a]	4.29[b]	6.44[a]
0.20% Na Bicarbonate	66.61[a]	68.04[a]	16.70[a]	25.08[a]	4.26[b]	6.39[a]
MAIN EFFECTS						
Peterson × Arbor Acres	65.61[a]	67.53[a]	14.22[a]	21.67[a]	3.82[a]	5.83[a]
Ross × Ross	66.57[b]	68.02[b]	16.66[b]	25.02[b]	4.27[b]	6.42[b]
Control	65.94[a]	67.62[a]	15.30[a]	23.19[a]	4.11[a]	6.24[a]
0.20% Na Bicarbonate	66.24[a]	67.93[a]	15.57[a]	23.50[a]	3.98[a]	6.01[a]

[A]Starter feeds contained bacitracin MD at 50 g/ton. Starter and grower feeds contained salinomycin at 60 g/ton. Ten males and ten females were sampled per replicate pen for processing.

[a,b]Means in a column and group without a common superscript differ significantly by the Least Significant Difference Procedure ($P < .05$).

duced coccidial lesion scores and mortality, increased final body weight, and improved mortality-adjusted feed efficiency, averaging across both strains.

Dietary sodium bicarbonate (0.2%) significantly increased chilled carcass as a percentage of live weight in Peterson × Arbor Acres chickens (Table 6). It was found from main effect means that Ross × Ross broilers had significantly higher dry carcass, chilled carcass, dry breast, chilled breast, dry fat pad, and chilled fat pad yields as percentages of live weight than did the Peterson × Arbor Acres birds.

EXPERIMENT 93-06

The December–January study at PARC Institute used 0, 0.2, or 0.3% dietary sodium bicarbonate with salinomycin at 60 g/ton, and there was a salinomycin negative control. Broilers were kept in built-up litter pens and inoculated with coccidia via drinking water at 14 days of age. Results are shown in Table 7. Salinomycin addition significantly improved coccidial lesion scores, feed efficiency, and mortality-adjusted feed efficiency. A level of 0.2% dietary sodium bicarbonate significantly improved coccidial lesion score, feed efficiency, and mortality compared to control results. The 0.3% dietary sodium bicarbonate treatment significantly improved coccidial lesion score, body weight, feed efficiency, mortality adjusted feed efficiency, and mortality compared to control values.

Linear regression analysis showed that increasing dietary sodium bicarbonate produced significant trends in coccidial lesion scores ($P < .001$; $R^2 = .661$; decreased), body weight ($P = .004$; $R^2 = .323$; increased), feed efficiency ($P < .001$; $R^2 = .549$; FCR decreased), mortality-adjusted feed efficiency ($P = .002$; $R^2 = .349$; FCR decreased), and mortality ($P < .001$; $R^2 = .579$; decreased).

In these studies, there was a beneficial synergistic effect when an ionophore coccidiostat, either monensin or salinomycin, was fed in combination with a level of 0.20% or more sodium bicarbonate. It may be termed an "ionophore-potentiating" effect. This generally resulted in lower coccidial lesion scores

TABLE 7. Effects of dietary sodium bicarbonate at 0, 0.2, or 0.3%, with or without salinomycin at 60 g/ton of feed, on 21-day coccidial lesion scores and 45-day productive performance of broiler chickens in built-up litter pens and given a coccidial challenge via water at 14 days of age (Experiment 93-06; PARC Institute; December 14, 1993–January 28, 1994)

DIETARY TREATMENT[A]		COMPOSITE COCCIDIAL LESION SCORE[B]	BODY WEIGHT	FEED/BODY WEIGHT	MORTALITY-ADJUSTED FEED/BODY WEIGHT	MORTALITY
Na Bicarbonate	Salinomycin					
%	g/ton		Lb	Lb/Lb	Lb/Lb	%
0	0	3.41[d]	4.278[a]	2.026[a]	1.940[a]	11.04[a]
0	60	2.72[c]	4.309[ab]	1.976[b]	1.885[b]	9.91[a]
0.20	60	2.19[b]	4.377[b]	1.919[c]	1.860[bc]	4.15[b]
0.30	60	1.69[a]	4.429[c]	1.888[c]	1.832[c]	3.85[b]
LINEAR REGRESSION						
Probability		< 0.001	0.004	< 0.001	0.002	< 0.001
R^2		0.661	0.323	0.549	0.349	0.579
Prediction: Constant		+2.752	+4.308	+1.977	+1.887	+9.542
NaBicarbonate % x		–3.326	0.389	–0.292	–0.168	–21.436

[A]All feeds contained bacitracin MD at 50 g/ton. Salinomycin was included at 0 or 60 g/ton in all feeds. There were eight replicates of 90 birds each per treatment (45 males + 45 females). Regression prediction coefficents in a column should be combined to determine the dependent variable.

[B]Average total coccidial lesion scores for upper, middle, and lower small intestine and ceca, using 0 to 4, least to most severe.

[a–d]Means in a column without a common superscript differ significantly by the Least Significant Difference Procedure ($P < .05$).

and mortalities, and improved body weights, feed efficiencies, and processing yields. Based on unpublished research at USDA, Augustine [7] proposed a mode of action whereby sodium bicarbonate may actually enhance coccidial invasion for rapid and early immunity development, giving the birds strong protection against further challenges. It is not clear whether sodium, bicarbonate, or the combination of ions is involved. In the Augustine scenario, dietary sodium bicarbonate would be of assistance to chicks as soon as they are given feed and exposed to built-up litter with oocysts residing there.

Conclusions and Applications

1. The optimal range of dietary sodium bicarbonate for production and processing improvements was 0.20% to 0.30% with an ionophore coccidiostat, either monensin or salinomycin, during all phases of growth and across all seasons when broilers were grown on built-up litter.
2. In several cases, linear and/or polynomial regression analysis indicated that addition of sodium bicarbonate (0.2 to 0.4%) yielded significant benefits and/or trends in body weight, feed efficiency, coccidial lesion scores, mortality, carcass yield, breast yield, and occasionally, abdominal fat pad.
3. Sodium bicarbonate potentiated salinomycin (60 g/ton), but whether the effective ion is Na^+, HCO_3-, or both is not known. Based on an unpublished 1997 study with sodium bicarbonate and monensin, Augustine [7] at USDA has proposed that enhanced coccidial invasion into intestinal epithelium results in rapid early immunity and stronger resistance to subsequent coccidial challenges.
4. Ross × Ross chicks with higher lean gain potential had heavier body weight, carcass yield, and breast yield than Peterson × Arbor Acres chicks. In response to 0.2% dietary sodium bicarbonate, Ross × Ross broilers had significantly better weight and feed efficiency, and both crosses had significantly improved coccidial lesion scores and mortalities compared to control treatments.

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