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Effect of Dietary Sodium Zeolite A on Zinc Utilization by Chicks[1]

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ABSTRACT Two experiments were conducted with chicks from 5 to 15 days posthatching to study the effect of sodium zeolite A (SZA) on Zn utilization. The corn-soybean meal basal diet was supplemented with $ZnCO_3$ to provide three levels of dietary Zn (35, 40, and 85 ppm) in Experiment 1, and two levels of dietary Zn (85 and 4,000 ppm) in Experiment 2. Experimental diets also contained either 0 or .75% SZA, resulting in a 3 × 2 and a 2 × 2 factorial arrangement of treatments in Experiments 1 and 2, respectively. The tendency for increased growth, feed intake, and hematocrit in chicks fed Zn-supplemented diets in Experiment 1 suggests that the 35-ppm level of Zn in the basal diet was marginal for chicks. Both supplemental Zn and SZA increased ($P < .02$) hematocrit and plasma, pancreas, and tibia Zn and decreased ($P < .02$) tibia Cu. Sodium zeolite A increased (SZA by Zn, $P < .03$) tibia Al and tended to increase (SZA by Zn, $P < .09$) liver Fe in chicks fed either 35 or 85 ppm Zn, but SZA had no effect on tibia Al and liver Fe in chicks fed 40 ppm Zn. In Experiment 2, both SZA and excess dietary Zn decreased gain, feed intake, gain: feed, hematocrit, hemoglobin, and plasma alkaline phosphatase (AP) activity, and increased tibia, liver, and pancreas Zn, and tibia Al. In addition, excess Zn increased ($P < .05$) plasma Zn and liver Al but decreased ($P < .01$) plasma, liver, and pancreas Cu and percentage of tibia ash. The addition of SZA enhanced the adverse effects of excess Zn by further decreasing feed intake, hematocrit, hemoglobin, and plasma AP and Cu and by increasing tibia Al and liver Zn. Sodium zeolite A increased pancreas ($P < .09$) and tibia ($P < .03$) Zn regardless of dietary Zn concentration; however, SZA increased plasma Zn only in chicks fed 85 ppm Zn (SZA by Zn, $P < .03$). Sodium zeolite A tended to improve Zn utilization in chicks fed inadequate Zn but exacerbated the adverse effects of feeding excess Zn. The addition of SZA to the diet of chicks fed inadequate, adequate, or toxic levels of Zn resulted in increased tissue Zn concentration.
(*Key words*: zeolite, zinc, bone ash, chicks, aluminum)

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INTRODUCTION

Sodium zeolite A[4] (SZA), a synthetic hydrated sodium aluminosilicate, molecular formula: $Na_{12}[(AlO_2)_{12}(SiO_2)_{12}]\cdot 27H_2O$, can lose and gain water and exchange cations without disrupting its molecular structure (Breck, 1974). The effects of dietary SZA on poultry have been investigated extensively. Because SZA has a high ion selectivity for Ca, most of the research has concentrated on the effects of SZA on Ca and P utilization, eggshell quality, and bone development, composition, and strength. Sodium zeolite A also exchanges associated cations with Zn, and Zn is ranked first on the cation selectivity profile of SZA (Zn > Sr > Ba > Ca > Co >

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[4]Sodium zeolite A (Ethacal® feed component) is a product of Ethyl Corp., Baton Rouge, LA 70801.

Ni > Cd > Hg). However, few studies have specifically investigated the effects of SZA on Zn utilization. Ward *et al.* (1990) and Watkins and Southern (1991) reported that the concentration of Zn in bone was increased in chicks fed SZA, and others have reported that SZA increases bone Zn (Ward *et al.*, 1991) and liver Zn (Pond and Yen, 1983) in pigs. Chiang and Yeo (1983) also reported that a naturally occurring zeolite increased Zn utilization in broilers. Therefore, the present study was conducted to determine whether dietary SZA influences tissue Zn concentration in chicks fed inadequate, adequate, or excess dietary levels of Zn. The influence of dietary SZA, Zn, and their interactive effects on growth, plasma constituents, and tissue trace mineral concentrations were evaluated.

MATERIALS AND METHODS

Male and female Arbor Acres × Peterson broiler chicks from a commercial hatchery[5] were used in this investigation. From hatching to 4 days posthatching, chicks in Experiment 1 were fed a corn-soybean meal diet (Table 1) without supplemental Zn (35 ppm total dietary Zn), and chicks in Experiment 2 were fed a corn-soybean meal diet (Table 1) containing 85 ppm total dietary Zn. After feed was removed overnight, chicks were weighed and assigned randomly to treatment groups on the basis of body weight (average initial weight was 73.8 g in Experiment 1 and 70.0 g in Experiment 2). Chicks were provided continuous fluorescent lighting and penned in heated, thermostatically controlled (mean temperature 35 C), stainless steel brooder batteries with raised wire floors. Four replicates of five chicks each were assigned to each treatment and fed their experimental diets from 5 to 15 days posthatching. Chicks were allowed *ad libitum* access to feed and water.

The treatment diets used in Experiment 1 were formulated to contain three levels of dietary Zn (35, 40, and 85 ppm) and two levels of SZA (0 and .75%) resulting in a 3 × 2 factorial arrangement of treatments. The 35-ppm level of Zn provided 88% of the Zn requirement for chicks [National Research Council (NRC), 1984]. In Experiment 2, the treatments diets were formulated to contain two levels of dietary Zn (85 and 4,000 ppm) and two levels of SZA (0 and .75%) resulting in a 2 × 2 factorial arrangement of treatments. Supplemental dietary Zn was provided by the addition of reagent grade $ZnCO_3$ (certified zinc carbonate).[6] Additions of $ZnCO_3$ and SZA were made to the basal diet (Table 1) at the expense of silica flour.[6]

At the termination of each experiment, individual chick weights and pen feed consumption were determined and a blood sample (2 mL) was taken from each chick via cardiac puncture. Hematocrit and total hemoglobin (cyanmethemoglobin method[7]) were determined on fresh blood. Plasma was collected and alkaline phosphatase (AP) activity was determined (Bowers and McComb, 1966). The remainder of the plasma was frozen for subsequent mineral analyses.

After bleeding, the chicks were killed by cervical dislocation, and the liver, pancreas, and left tibia were removed for subsequent analyses. Tibiae were cleaned of adherent tissue, extracted (Soxhlet) continuously for 48 h in 90% ethanol and then for 48 h in anhydrous diethyl ether, and dried at 90 C for 24 h. The dry, fat-free tibiae were weighed and dry-ashed at 590 C for 20 h. Pancreata and livers were dried at 90 C for 24 h, weighed, and wet-ashed with HNO_3 and H_2O_2. The resulting tissue residue was solubilized in trace metal grade concentrated hydrochloric acid[6] and diluted to a standard volume with deionized water.

The Zn and Cu content of the tibia ash, plasma, and pancreas were determined by flame atomic absorption spectroscopy.[8] Tibia ash Al, and liver Zn, Cu, Fe, and Al were determined using an inductively coupled plasma spectrophotometer.[9]

[5]Sanderson Farms, Laurel, MS 39440.

[6]Fisher Chemical Co., Pittsburgh, PA 15219.

[7]Sigma Chemical Co., St. Louis, MO 63178-9916.

[8]Model 3030B, Perkin-Elmer Corp., Norwalk, CT 06859.

[9]Series 800 Plasma AtomComp Direct-Reading Spectrometer, Thermo Jarrell-Ash Corp., Franklin, MA 02038.

TABLE 1. Dietary composition

Ingredients and analysis	Experiment 1	Experiment 2
	(%)	(%)
Corn	46.39	45.64
Soybean meal (44% CP)	42.50	42.50
Corn oil	5.00	5.00
Alfalfa leaf meal	2.00	2.00
Defluorinated rock phosphate	2.10	2.10
Limestone	.40	.40
NaCl	.40	.40
Vitamin mix[1]	.25	.25
DL-methionine	.15	.15
$MnSO_4 \cdot H_2O$	.05	.05
$ZnCO_3$	...	.01
Treatment additions[2]	.76	1.50
Calculated analysis		
CP	23.00	23.00
ME, kcal/kg	3,000	3,000
Calcium	1.00	1.00
Available phosphorus	.50	.50
Methionine + cystine	.89	.89
Lysine	1.48	1.48

[1]Roche Chemical Division, Nutley, NJ 07110. Provided the following per kilogram of diet: retinyl acetate, 6,614 IU; cholecalciferol, 1,653 IU; dl-α-tocopheryl acetate, 7 IU; vitamin B_{12}, 11 μg; riboflavin, 6.6 mg; niacin, 33.1 mg; d-pantothenic acid, 11.0 mg; choline, 551 mg; menadione, 1.5 mg; folic acid, .7 mg; pyridoxine, 1.1 mg; thiamin, 1.1 mg; d-biotin, 55 μg.

[2]Zinc carbonate ($ZnCO_3$) was added to the basal diet at the expense of silica flour in order to provide the desired dietary Zn concentrations. These diets were then divided, and either silica flour or SZA was added to provide the 0 and .75% SZA diets. In Experiment 1, the 35, 40, and 85 ppm diets were analyzed to contain 34.9, 41.9, and 81.2 ppm Zn, respectively. In Experiment 2, the 85 and 4,000 ppm diets were analyzed to contain 86.5 and 4,008 ppm Zn, respectively.

Data were analyzed by analysis of variance procedures for a factorial arrangement of treatments in a completely random design (Steel and Torrie, 1980). Orthogonal, single degree of freedom comparisons were used to test main effects and interactions. Data were evaluated for homogeneity of variance and, when appropriate, were transformed prior to statistical analyses [log (y + 1), Steel and Torrie, 1980]. Pen means (four per treatment group) were used as the experimental unit for all data.

RESULTS

Experiment 1. Inadequate Zinc

The dietary addition of SZA had no effect ($P > .10$) on gain, feed intake, or gain:feed ratio regardless of dietary Zn level (Table 2). Incremental addition of Zn to the basal diet tended to improve gain and feed intake; however, this improvement was greater between 35 and 40 ppm Zn than between 40 and 85 ppm Zn (Zn quadratic, $P < .10$). Dietary Zn concentration had no effect ($P > .10$) on gain:feed ratio.

Dietary addition of SZA increased hematocrit ($P < .01$) and tended to increase blood hemoglobin ($P < .08$) concentration (Table 3). The initial supplementation of the basal diet with 5 ppm Zn (40 ppm total dietary Zn) increased hematocrit and blood hemoglobin concentration, whereas further Zn supplementation had no effect on hematocrit (Zn quadratic, $P < .01$) and tended to decrease blood hemoglobin concentration (Zn quadratic, $P < .08$). Plasma AP and Cu were not ($P > .10$) influenced by either dietary Zn or SZA (Table 3). Plasma Zn (Table 3) was increased by the dietary supplementation of Zn (Zn linear, $P < .02$) and SZA ($P < .01$). However, dietary addition of Zn at 5 ppm (from 35 to 40 ppm) resulted in an increased plasma Zn concentration in chicks not fed SZA, but no change in plasma Zn concentration of chicks fed .75% SZA (SZA by Zn quadratic, $P < .09$).

Neither SZA or Zn affected ($P > .10$) percentage tibia ash, tibia Fe, or liver Zn, Cu, and Al (Table 4). However, both SZA and Zn supplementation increased ($P < .01$) tibia and pancreas Zn concentration. Dietary SZA decreased ($P < .01$) tibia Cu and increased ($P < .03$) pancreas Cu but had no effect ($P > .20$) on liver Cu concentrations. Supplementing the basal diet with 5 ppm Zn (40 ppm total dietary Zn) decreased tibia Cu, but further Zn supplementation reduced tibia Cu to a lesser degree (Zn quadratic, $P < .04$). Dietary Zn supplementation had no effect ($P > .50$) on liver and pancreas Cu concentrations. The addition of SZA to the diet of chicks fed either 35 or 85 ppm Zn tended to increase liver Fe concentration; however, SZA had no effect on liver Fe concentration in chicks fed 40 ppm Zn (SZA by Zn, $P < .09$). Dietary SZA

TABLE 2. Gain, feed intake, and gain:feed of chicks fed graded levels of zinc with and without sodium zeolite A (SZA), Experiment 1[1]

Zn	SZA	Gain	Feed	Gain:feed
(ppm)	(%)	(g)		(g:g)
35	0	251	341	.736
40	0	272	366	.743
85	0	269	357	.753
35	.75	237	314	.752
40	.75	264	350	.754
85	.75	272	360	.755
SEM		13	15	.009
Main effects				
Zn				
35		244	328	.744
40		268	358	.749
85		271	359	.754
SZA				
0		264	355	.744
.75		258	341	.754
Source of variation		Probability		
SZA		.529	.295	.194
Zn linear		.158	.189	.290
Zn quadratic		.097	.075	.693
SZA × Zn linear		.513	.358	.436
SZA × Zn quadratic		.867	.813	.807

[1]Data are means of four replicates of five chicks each during the period 5 to 15 days posthatching. Average initial weight on Day 5 was 73.8 g.

TABLE 3. Hematocrit and hemoglobin and plasma concentrations of alkaline phosphatase, zinc, and copper of chicks fed graded levels of zinc with and without sodium zeolite A (SZA), Experiment 1[1]

Zn	SZA	Hematocrit	Hemoglobin	Alkaline phosphatase	Zn	Cu
(ppm)	(%)		(g/dL)	(IU/L)	(μg/mL)	(μg/dL)
35	0	26.50	8.55	3,968	1.48	19
40	0	28.38	9.32	4,603	2.03	16
85	0	28.50	8.60	2,707	2.13	16
35	.75	28.88	9.19	3,300	2.43	16
40	.75	30.88	9.45	3,544	2.43	15
85	.75	30.50	9.13	3,546	2.70	17
SEM		.45	.28	595	.15	1
Main effects						
Zn						
35		27.69	8.87	3,634	1.96	18
40		29.63	9.39	4,074	2.23	16
85		29.50	8.87	3,127	2.42	17
SZA						
0		27.79	8.82	3,759	1.88	17
.75		30.09	9.26	3,463	2.52	16
Source of variation		Probability				
SZA		.001	.079	.550	.001	.203
Zn linear		.020	.372	.197	.014	.885
Zn quadratic		.001	.074	.399	.120	.125
SZA × Zn linear		.591	.830	.124	.582	.099
SZA × Zn quadratic		.852	.373	.639	.084	.303

[1]Data are means of four replicates of five chicks each.

TABLE 4. Tissue mineral concentrations of chicks fed graded levels of zinc with and without sodium zeolite A (SZA), Experiment 1[1]

		Tibia					Liver				Pancreas	
Zn	SZA	Ash	Zn	Cu	Fe	Al	Zn	Cu	Fe	Al	Zn	Cu
(ppm)		(%)	(μg/g of ash)				(μg/g of dry tissue)					
35	0	51.5	322.3	5.68	190.2	39.85	83.5	12.07	146.6	24.53	106.8	4.48
40	0	52.3	395.4	4.71	221.2	50.07	73.8	12.88	157.6	13.07	118.4	4.40
85	0	51.6	443.9	4.18	218.9	39.28	79.2	13.07	137.4	9.54	145.5	4.63
35	.75	51.5	464.2	4.49	208.9	65.75	81.6	13.94	256.7	21.74	163.0	4.87
40	.75	50.7	487.5	3.10	215.6	50.01	79.1	12.31	159.7	14.86	171.1	4.83
85	.75	51.0	512.0	2.89	208.5	46.55	78.7	12.32	160.2	14.26	183.7	4.90
SEM		.5	18.3	.47	14.7	5.19	5.8	.97	28.6	6.45	7.5	.19
Main effects												
Zn												
35		51.5	393.3	5.09	199.6	52.80	82.6	13.0	201.7	23.14	134.9	4.68
40		51.5	441.5	3.91	218.4	50.04	76.5	12.6	158.7	13.97	144.8	4.62
85		51.3	478.0	3.53	213.7	42.92	79.0	12.7	148.8	11.90	164.6	4.77
SZA												
0		51.8	387.2	4.86	210.1	43.07	78.8	12.7	147.2	15.71	123.6	4.50
.75		51.1	487.9	3.49	211.0	54.10	79.8	12.8	192.2	16.95	172.6	4.87
Source of variation		Probability										
SZA		.880	.001	.002	.943	.018	.843	.822	.070	.817	.001	.028
Zn linear		.669	.001	.018	.631	.069	.844	.871	.180	.205	.001	.494
Zn quadratic		.189	.059	.033	.230	.725	.314	.689	.183	.207	.344	.689
SZA × Zn linear		.162	.157	.929	.468	.405	.871	.258	.412	.625	.218	.677
SZA × Zn quadratic		.695	.350	.646	.455	.026	.531	.254	.086	.760	.907	.870

[1]Data are means of four replicates of five chicks each.

TABLE 5. Gain, feed intake, and gain:feed of chicks fed 85 and 4,000 ppm zinc with and without sodium zeolite A (SZA), Experiment 2[1]

Zn	SZA	Gain	Feed	Gain:feed
(ppm)	(%)	(g)		(g:g)
85	0	289	366	.789
4,000	0	195	299	.655
85	.75	267	351	.761
4,000	.75	154	260	.590
SEM		7	5	.019
Main effects				
Zn				
85		278	359	.775
4,000		175	280	.623
SZA				
0		242	333	.722
.75		211	306	.676
Source of variation		Probability		
SZA		.001	.001	.033
Zn		.001	.001	.001
SZA × Zn		.181	.047	.369

[1]Data are means of four replicates of five chicks each during the period 5 to 15 days posthatching. Average initial weight on Day 5 was 70.0 g.

increased tibia Al in chicks fed diets containing either 35 or 85 ppm Zn but had no effect on chicks fed diets containing 40 ppm Zn (SZA by Zn quadratic, $P < .03$).

Experiment 2. Excess Zinc

Chicks fed SZA, 4,000 ppm Zn, or the combination of these dietary additives had decreased ($P < .04$) gain, feed intake, and gain:feed ratios compared with chicks fed the 85 ppm Zn basal diet (Table 5). The excess Zn-induced reduction in feed intake was greater in chicks fed SZA (SZA by Zn, $P < .05$).

The dietary addition of SZA had no significant effect or tended to slightly increase hematocrit and hemoglobin in chicks fed 85 ppm Zn (Table 6), but markedly decreased these blood constituents in chicks fed 4,000 ppm Zn (SZA by Zn, $P < .03$). Sodium zeolite A decreased plasma AP in chicks fed 85 ppm Zn, but did not affect AP in chicks fed 4,000 ppm Zn (SZA by Zn, $P < .02$). Although SZA decreased plasma Zn and Cu in chicks fed excess Zn, it increased both of these plasma constituents in chicks fed diets containing 85 ppm Zn (SZA by Zn, $P < .03$). Excess Zn decreased ($P < .01$) hemoglobin, hematocrit, and plasma AP and Cu, and increased ($P < .01$) plasma Zn.

Chicks fed excess Zn had decreased ($P < .01$) tibia ash content, but SZA did not ($P > .20$) influence this response (Table 7). Dietary SZA increased ($P < .03$) the Zn content of tibia and liver, and tended ($P < .07$) to increase the Zn content of the pancreas (Table 7). Excess Zn decreased ($P < .01$) tibia Fe, and pancreas and liver Cu concentrations, and increased ($P < .05$) tibia, liver, and pancreas Zn, and liver Al concentrations. Both excess Zn and SZA slightly increased tibia Al concentration, but the two dietary additions in combination markedly increased tibia Al (SZA by Zn, $P < .01$). Excess Zn decreased tibia ash Ca levels in chicks not fed SZA but did not affect tibia ash Ca levels in chicks fed SZA (Figure 1).

DISCUSSION

The tendency for increased growth and feed intake in chicks fed Zn-supplemented diets in Experiment 1 suggests that the unsupplemented basal diet was marginal in Zn. Increases in hematocrit and hemoglobin levels and plasma, tibia, and pancreas Zn levels also suggest that the Zn content of the basal diet was not adequate. These results agree with the findings of O'Dell *et al.* (1958) and Young *et al.* (1958), who reported that the Zn requirement for

TABLE 6. Hematocrit and hemoglobin and plasma concentrations of alkaline phosphatase, zinc, and copper of chicks fed 85 and 4,000 ppm zinc with and without sodium zeolite A (SZA), Experiment 2[1]

Zn	SZA	Hematocrit	Hemoglobin	Alkaline phosphatase	Zn	Cu
(ppm)	——— (%) ———		(g/dL)	(IU/L)	(μg/mL)	(μg/mL)
85	0	27.88	11.49	5,211	2.08	10
4,000	0	19.75	7.29	1,531	6.93	4
85	.75	29.13	11.55	3,949	2.53	12
4,000	.75	15.00	5.34	1,642	5.98	2
SEM		.91	.40	230	.27	1
Main effects						
Zn						
85		28.51	11.52	4,580	2.31	11
4,000		17.38	6.32	1,587	6.46	3
SZA						
0		23.82	9.39	3,371	4.51	7
.75		22.07	8.45	2,796	4.26	7
Source of variation		———	———	Probability	———	———
SZA		.078	.037	.028	.373	.999
Zn		.001	.001	.001	.001	.001
SZA × Zn		.006	.028	.012	.024	.017

[1]Data are means of four replicates of five chicks each.

chicks fed diets based on soy protein was in the range of 30 to 50 ppm, and agree with the current NRC (1984) recommendation of 40 ppm. The excess Zn-induced reduction in gain, feed intake, and gain:feed ratios observed in Experiment 2 also has been reported by Johnson *et al.* (1962) and by Southern and Baker (1983).

Sodium zeolite A had no effect on gain, feed intake, and gain:feed ratio in Experiment 1 but reduced these variables in Experiment 2. In Experiment 2, SZA exacerbated the adverse effects of excess Zn on growth and feed efficiency.

Although dietary SZA had no effect on growth, feed intake, or feed efficiency in Experiment 1, plasma, tibia, and pancreas Zn concentrations were increased by SZA, indicating improved Zn utilization by chicks fed SZA. Dietary SZA also increased tibia, liver, and pancreas Zn content in Experiment 2 regardless of dietary Zn concentration. Previous studies have shown that SZA increases tibia Zn (Watkins and Southern, 1991), and Chiang and Yeo (1983) reported that a naturally occurring zeolite increased Zn utilization in chickens.

The activity of AP, a Zn-dependent metalloenzyme, has been shown to decrease in tissues of chickens fed Zn-deficient diets (Lease, 1972); however, plasma AP was not influenced by dietary Zn concentration in Experiment 1. The

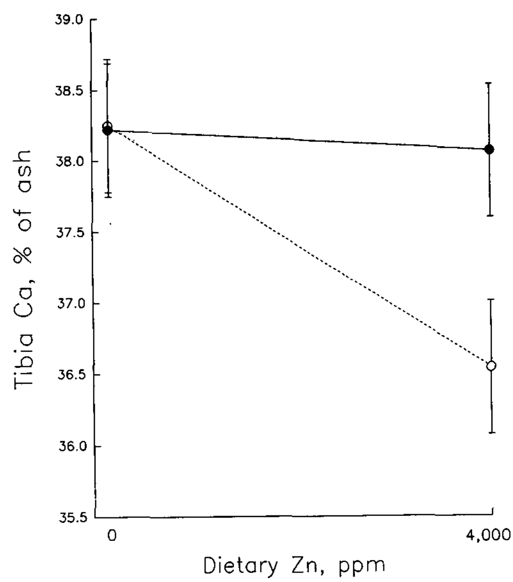

FIGURE 1. Tibia ash Ca content (± SEM) of chicks fed either 85 or 4,000 ppm Zn without (o, 0%) or with (•, .75%) sodium zeolite A.

lack of response in plasma AP activity in Experiment 1 may have occurred because the chicks were subjected only to marginal Zn inadequacy. In addition, Davies and Motzok (1971) reported that although tibia and intestinal AP activity decreased during severe Zn deficiency, liver AP increased. In Experiment 2, excess Zn (4,000 ppm) decreased both tibia ash and plasma AP. The reduced feed intake observed in chicks fed 4,000 ppm Zn might have influenced plasma AP activity, because starvation has been shown to reduce AP in chickens (Bide and Dorward, 1970).

Dietary Zn supplementation decreased tibia Cu concentrations in Experiment 1 and plasma, liver, and pancreas Cu concentrations in Experiment 2. The dietary addition of SZA exacerbated the Zn-induced reduction in tibia (Experiment 1) and pancreas (Experiment 2) Cu. Zinc is known to antagonize Cu utilization, possibly by way of induced metallothionein synthesis (Fischer *et al.*, 1983; Davis and Mertz, 1987), and excess Zn has been shown to reduce tissue Cu concentrations in chickens (Southern and Baker, 1983; Stahl *et al.*, 1989).

Excess Zn decreased hematocrit, hemoglobin, and tibia Fe, and numerically reduced liver Fe. Sodium zeolite A exacerbated the adverse effects of feeding 4,000 ppm Zn on hematocrit and hemoglobin but increased these blood variables and tended to increase liver Fe concentration in chicks fed dietary Zn levels between 35 and 85 ppm. Southern and Baker (1983) and Parsons *et al.* (1989) also found that excess Zn reduced hematocrit and hemoglobin in chicks. Zinc toxicity results in hyperchromic, mycrocytic anemia in rats, and Stahl *et al.* (1989) demonstrated that chicks fed excess Zn retained less ^{59}Fe and had lower tibia Fe concentrations.

The increased accumulation of Al in the tibia of chicks fed SZA has been reported previously by Watkins and Southern (1991) and by Leach *et al.* (1990). Excess Zn exacerbated the SZA-induced increase in tibia Al. The increased tibia Zn accumulation in chicks fed 4,000 ppm Zn may have been a result of a general detoxification response. If this induced accumulation of excess minerals in the bone is nonspecific, it might explain the subsequent increase in tibia Al accumulation. Tibia Pb and Mo concentrations also increased in the tibia of chicks fed excess Zn (tibia Pb and Mo concentrations for birds fed 0 and 4,000 ppm Zn were: Pb, 131.3 and 341.2 $\mu g/g$ ash, respectively; Mo, .59 and 4.14 $\mu g/g$ ash, respectively).

These studies demonstrate that SZA increases tissue Zn concentrations in chicks fed inadequate, adequate, and excess Zn. Sodium zeolite A tended to improve Zn utilization in chicks fed inadequate dietary Zn but exacerbated the adverse effects of feeding excess Zn. The ion exchange affinity of SZA for Zn might be responsible for this increase in Zn utilization because other metal-complexing agents have been shown to improve Zn utilization in birds (Vohra and Kratzer, 1964; Pimentel *et al.*, 1991). Oberleas *et al.* (1966) reported that EDTA increased Zn availability in the rat, possibly by competing with phytate and forming a Zn-EDTA complex, which improved Zn absorption. Pond and Yen (1983) suggested that the SZA-induced increase in liver Zn in pigs was due to selective binding and subsequent release of Zn by SZA at an intestinal site conducive to absorption.

In Experiment 2, excess Zn decreased tibia ash Ca levels in chicks not fed SZA but did not affect tibia ash Ca levels in chicks fed SZA (Figure 1). Excess Zn has been shown to increase lumenal P content in the intestine of the rat (Magee, 1985). The SZA or the Si or Al associated with SZA could bind with this excess P and prevent the formation of insoluble phosphate salts with cations such as Zn and Ca. This concept has been discussed in more detail by Elliot and Edwards (1991), Roland *et al.* (1991), and Watkins and Southern (1992), and suggests that the effect of SZA on Zn (and Ca) utilization may be a secondary response resulting from the effect of SZA on P and not a direct affinity for Zn per se. Results from a previous study support this theory by demonstrating that as dietary P is decreased, tibia Zn concentration is increased (Watkins and Southern, 1992).

In Experiment 1, plasma, tibia, and pancreas Zn concentrations were higher in chicks fed the 35-ppm Zn basal diet supplemented with SZA, than in chicks

TABLE 7. Tissue mineral concentration of chicks fed 85 and 4,000 ppm zinc with and without sodium zeolite A (SZA), Experiment 2[1]

		Tibia					Liver				Pancreas	
Zn	SZA	Ash	Zn	Cu	Fe	Al	Zn	Cu	Fe	Al	Zn	Cu
(ppm)		(%)	(μg/g of ash)				(μg/g of dry tissue)					
85	0	51.3	466.0	4.86	222.5	39.47	80.8	16.19	221.9	11.20	137.5	5.41
4,000	0	48.1	4,805.5	4.45	138.4	45.88	951.7	9.64	158.4	21.79	5,061.8	3.75
85	.75	50.7	529.3	5.15	236.3	51.83	88.7	14.99	281.9	16.50	162.6	4.81
4,000	.75	47.3	5,353.6	4.55	127.4	114.71	1,392.7	8.63	225.1	25.90	5,905.5	3.64
SEM		.7	215.9	.34	6.8	4.74	70.8	.90	36.8	4.43	192.5	.35
Main effects												
Zn												
85		51.0	497.7	5.01	229.4	45.65	84.8	15.59	251.9	13.85	150.1	4.98
4,000		47.7	5,079.6	4.50	132.9	80.30	1,172.2	9.14	191.8	23.85	5,483.7	3.70
SZA												
0		49.7	2,635.8	4.66	180.5	42.68	516.3	12.92	190.2	16.50	2,599.7	4.45
.75		49.0	2,941.5	4.85	181.9	83.27	740.7	11.81	253.5	21.20	3,034.1	4.23
Source of variation		Probability										
SZA		.239	.020	.573	.837	.001	.011	.246	.111	.309	.069	.546
Zn		.001	.001	.156	.001	.001	.001	.001	.128	.044	.001	.004
SZA × Zn		.860	.859	.779	.093	.001	.086	.918	.928	.896	.844	.756

[1]Data are means of four replicates of five pigs each.

fed the 85-ppm Zn diet without SZA. Because SZA increased plasma, tibia, and pancreas Zn even in chicks fed the basal diet that did not contain supplemental inorganic Zn, it probably exerted some of its effects on phytate associated Zn. Although SZA is devoid of Zn, these data suggest that SZA increased the bioavailability of dietary Zn.

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