ISSN 1682-8356
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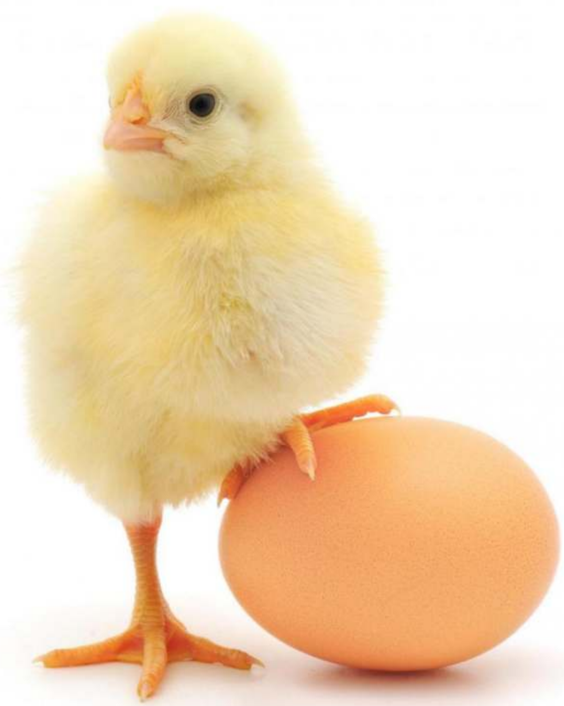

INTERNATIONAL JOURNAL OF
POULTRY SCIENCE

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International Journal of Poultry Science 4 (6): 399-407, 2005
ISSN 1682-8356

Influence of Sodium Source and Level on Performance of Second-Cycle Hens Fed Diets with Different Levels of Nonphytate Phosphorus

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Abstract: Hens of a commercial strain of SCWL hens were subjected to a molt and allowed to resume production before being placed on test diets consisting of a nutritionally complete basal diet supplemented with three sources of sodium (sodium chloride, sodium bicarbonate, and sodium sulfate) at three levels of added sodium (0.10, 0.20, 0.30%) with three levels of nonphytate phosphorus (0.25, 0.45, and 0.65%) in a complete factorial arrangement. When non-chloride sources of sodium were used the diet was supplemented with 0.12% Cl from calcium chloride. A reference group of hens within each level of nonphytate phosphorus was fed a diet with no supplemental sodium or chloride. Each of the thirty resulting dietary treatments was assigned to eight groups of hens, with a replicate group consisting of five 30.5 x 45.7 cm cages with one hen per cage fed from a common feed container. After allowing the hens to acclimate to the test diets for 28 d data were collected for a second 28 d period on rate of egg production, feed intake, egg weight, shell breaking force, and shell deformation time. Results of the study indicate that no more than 266 mg/d of nonphytate P was adequate for egg production. Increasing the dietary P level greater than 0.45% nonphytate P resulted in a significant reduction in egg shell strength. A dietary sodium intake of 128 mg/d appeared adequate to support optimum performance. Use of sodium bicarbonate or sodium sulfate in place of sodium chloride appeared to have no benefits in regard to egg shell strength in this study.

Key words: Second cycle hens, phosphorus, sodium, shell strength, deformation

Introduction

The interrelationship of calcium and phosphorus in eggshell formation has been well documented (Wolford and Tanaka, 1970; Summers *et al*., 1976; Härtel, 1990; Roland, 1986; Keshavarz and Nakajima, 1993). Several reports (Choi *et al*., 1980; Choi and Han, 1983; Damron and Harms, 1980; Miles and Harms, 1982; Junqueira *et al*., 1984) have suggested an interrelationship between Na and P in eggshell formation. Both sodium chloride and sodium bicarbonate are often used as sources of sodium for layer diets, with some suggestions that the use of sodium bicarbonate may aid in promoting better egg shell calcification, especially in heat stress situations (Makled and Charles, 1987; Balnave and Muheereza, 1997). The objective of the present study was to examine the relationship between sodium source and level and the phosphorus content of the diet on rate of egg production, feed utilization, and shell strength in egg-type laying hens in their second cycle of production.

Materials and Methods

A diet was formulated that was calculated to contain 16% crude protein, 2,850 ME kcal/kg, 3.25% Ca, 0.45% total P, and 0.25% nonphytate P (NPP). This level of calcium was considered marginal in order to make the diet more sensitive to factors that might influence the shell calcification. Composition of the diet is shown in Table 1. Analyzed levels of CP, Ca, and total P were close to calculated values. The diet was determined by analysis to contain 0.02% Na and 0.04% Cl. The diet was calculated to meet or exceed recommended levels of essential amino acids (NRC, 1994) and was fortified with complete vitamin and trace mineral premixes. Washed builders sand was included as a nonnutritive filler to allow for supplementation with additional sources of phosphorus, sodium, and chloride.

Hens used in the study were a commercial strain of egg-production type hens[2] that had completed a 252-day test commencing at 140 d of age. During this time the hens had been fed a diet similar to that in Table 1, but containing 0.45% NPP and 0.375% added salt. The hens were then molted by restriction of feed and light. They were then held out of production by restricting light to less than 6 hours per day for six wk during which time they were fed a standard pullet growing feed containing 1% Ca, 0.45% NPP, and 0.375% added salt. Following the six wk post-molt period, the hens were placed on the diet shown in Table 1, with a NPP content of 0.45% and addition of sufficient salt to bring the calculated dietary Na level to 0.15%. The lighting schedule was increased to 14 hr daily. The hens were allowed to return to production; any hen that did not resume production or was in poor physical condition was removed from the flock.

For a two-week pretest period, records were maintained on rate of production and feed intake. All eggs laid

Table 1: Composition and nutritional analysis of basal diet

Ingredient		% of diet	
Ground yellow corn		70.14	
Soybean meal, dehulled		18.20	
Ground limestone		8.29	
Dicalcium phosphate		0.84	
Trace mineral mix[1]		0.10	
Vitamin premix[2]		0.50	
Washed sand		1.93	
Total weight		100.00	
Nutrient	Unit	Quantity	Basis[3]
Metabolizable energy	Kcal/kg	2850.00	C
Crude protein	%	16.23	A
Calcium	%	3.27	A
Total phosphorus	%	0.48	A
Nonphytate phosphorus	%	0.25	C
Arginine	%	1.02	C
Lysine	%	0.75	C
Methionine	%	0.27	C
TSAA	%	0.51	C
Tryptophan	%	0.18	C
Sodium	%	0.02	A
Chloride	%	0.04	A

[1]Provided per kg of diet: 100 mg iron; 100 mg zinc, 100 mg manganese, 10 mg copper, 1 mg iodine.
[2]Provided per kg of diet: 6,600 IU vitamin A; 2,200 IU vitamin D_3; 3.3 IU vitamin E; 1.1 mg menadione; 3.3 mg riboflavin; 8.8 mg niacin; 3.3 mg d-pantothenic acid; 330 mg choline; 1.1 mg thiamin; 1.1 mg pyridoxine; 5.5 mg (mcg) vitamin B_{12}; 0.11 mg (mcg) d-biotin; 0.22 mg folic acid; 62.5 mg ethoxyquin as a preservative.
[3]C = calculated from NRC (1994); A = analyzed value from commercial laboratory.

during this time were collected and held overnight in a refrigerated egg room (5°C). The following day they were individually weighed and the shell breaking strength and deformation determined using the instrument described by Voisey and MacDonald (1978). At the end of the pretest period the groups of hens were assigned at random to the test diets. Due to the large volume of data to be processed it was not possible to assign dietary treatments to groups based on comparable egg production or egg quality status. Covariance analysis was used if any significant pretest differences occurred. For the eight-week test interval, the hens were fed three levels of NPP (0.25, 0.45, and 0.65%). These levels were attained by varying the amount of dicalcium phosphate, with adjustment in the amounts of ground limestone and washed sand as needed to maintain the dietary Ca at 3.25%. Within each NPP series, one group of hens was fed the diet with no supplemental Na or Cl. This group served as the negative control to demonstrate the deficiency of Na and/or Cl; the hens fed these diets quickly responded to the deficiency by markedly reducing their feed intake and rate of egg production. The data from this group of hens were not included in the statistical analysis.

Additional groups of hens within each NPP level received dietary supplementation of 0.10, 0.20, and 0.30% Na from reagent grade sources of sodium chloride, sodium bicarbonate, and sodium sulfate. Since the bicarbonate and sulfate sources did not supply Cl, diets containing these two products were supplemented with 0.12% Cl from calcium chloride to meet the needs for this ion.

The combination of three levels of NPP, three sodium sources, and three sodium levels, and the three negative control diets resulted in a total of 30 treatments. Each treatment was fed to eight replicate groups of hens, with each group consisting of a series of five 30.5 x 45.7 cm cages with one hen per cage, fed from a common feed container. The cages were located in a totally enclosed house with thermostatically controlled fans and space heaters to maintain environmental temperature. During the test period, the mean daily house temperature was 20.2°C.

Records were maintained of rate of egg production and feed consumed by replicate groups. The first 28 d was considered as an acclimation period to the test diets. From 28 to 56 d all eggs produced were collected and held overnight in the refrigerated egg cooler at 5°C. The following day the eggs were individually weighed and evaluated for breaking strength and deformation as previously described.

Pen means served as the experimental unit for statistical analysis. Data were analyzed as a complete factorial using the General Linear Models option of SAS (SAS Institute, 1991). Main effects of nonphytate P level, sodium level, and sodium source as well as all two-way and three-way interactions were examined. Significant differences among treatments were separated by repeated t-tests using the lsmeans option of SAS. Statements of probability were based on P £ 0.05. Results for the statistical analysis of various parameters are shown in Table 2.

Results

Evaluation of response to Na and NPP levels must be based on actual consumption levels. Mean daily intake levels for the period of 28 to 56 d on test are shown in Table 3 for NPP and Table 4 for sodium. NPP intakes were 266, 494, and 676 mg/day for the hens fed diets with 0.25, 0.45, and 0.65% NPP, respectively. The 266 mg/day NPP is near the 250 mg/day intake suggested by NRC (1994). Level or source of sodium had no effect on NPP intake. Mean sodium intakes were 128, 236, and 340 mg/day for diets with 0.10, 0.20, and 0.30%, respectively, as compared to the 150 mg/day suggested by NRC (1994).

Hen-day egg production: Rate of egg production over the test period is shown in Table 5. Diets with 0.25% NPP, providing an average of 266 mg/day, supported production equal to that of hens fed diets with 0.45%

Table 2: Statistical analysis of various parameters from the 28th to the 56th day by second-cycle hens fed the test diets

Source of variation	Df	Probability > F				
		Egg production	Feed intake	Egg Weight	Breaking Force	Shell deformation
Phosphorus level (PL)	2	0.01	0.01	0.63	0.01	0.03
Sodium level (SL)	2	0.53	0.87	0.32	0.92	0.02
PL x SL	4	0.62	0.63	0.93	0.40	0.74
Sodium source (SS)	2	0.72	0.54	0.29	0.26	0.21
PL x SS	4	0.05	0.67	0.18	0.24	0.14
SL x SS	4	0.03	0.97	0.96	0.01	0.20
PL x SL x SS	8	0.20	0.17	0.60	0.09	0.26

Table 3: Mean daily nonphytate phosphorus intake (mg/day) from the 28th to the 56th day of second-cycle hens fed the test diets

% Nonphytate Phosphorus	% Added Sodium	Sodium source			Mean
		Sodium Chloride	Sodium Bicarbonate	Sodium Sulfate	
0.25	0.10	271	260	265	266
0.25	0.20	267	269	268	268
0.25	0.30	261	262	276	266
	Mean	266	264	270	266
0.45	0.10	495	508	484	489
0.45	0.20	504	485	504	498
0.45	0.30	488	498	502	496
	Mean	489	497	497	494
0.65	0.10	703	658	709	690
0.65	0.20	658	685	676	673
0.65	0.30	698	644	655	666
	Mean	686	662	680	676
-----	0.10	489	475	486	482
-----	0.20	476	480	483	480
-----	0.30	482	468	478	476
	Mean	482	474	482	

NPP providing an average of 494 mg/day. This supports the NRC (1994) recommendation of 250 mg/day. Increasing the NPP to 0.65% significantly decreased the rate of egg production

The sodium content of the diet had no significant effect on rate of egg production, indicating that the minimum sodium intake of 128 mg/day was satisfactory under the test conditions. This is less than the 150 mg/day recommended by NRC (1994). There was no effect of sodium source on rate of egg production. A significant interaction was observed between sodium source and NPP level (Fig. 1); when diets contained 0.25 or 0.65% NPP egg production was highest when hens were fed sodium chloride as a source of sodium. However, when diets contained 0.45% NPP the egg production was lowest when hens were fed sodium chloride as a source of sodium, as compared to hens fed sodium bicarbonate or sodium sulfate. There was also an interaction between sodium source and sodium level for egg production (Fig. 2). When diets contained 0.1 or 0.3 % added sodium there was little difference in rate of egg production among hens fed the various sources of sodium; however, when the diets contained 0.2% added sodium egg production of hens fed sodium chloride was higher than that of hens fed sodium bicarbonate with production of hens fed sodium sulfate the lowest among the different sources.

Daily feed intake: Daily feed intake was significantly influenced only by the NPP content of the diet (Table 6). Hens fed the diets with 0.45% NPP consumed significantly more feed than those fed diets with 0.25 or 0.65% NPP with no significant difference in feed intake between hens fed diets with 0.25 or 0.65% NPP. Source or level of sodium had no significant effect on feed intake. No interactions among or between sodium level and source and level of NPP were observed related to daily feed intake.

Egg weight: None of the dietary factors had any

Table 4. Mean daily sodium intake (mg/day) from the 28th to the 56th day of second-cycle hens fed the test diets

% Nonphytate Phosphorus	% Added Sodium	Sodium source			Mean
		Sodium Chloride	Sodium Bicarbonate	Sodium Sulfate	
0.25	0.10	130	125	127	127
0.25	0.20	235	236	235	235
0.25	0.30	334	335	353	341
	Mean	233	232	238	234
0.45	0.10	127	136	129	130
0.45	0.20	246	237	246	243
0.45	0.30	347	354	357	353
	Mean	240	242	244	242
0.65	0.10	130	121	131	127
0.65	0.20	222	232	229	228
0.65	0.30	344	317	322	328
	Mean	232	223	227	228
-----	0.10	129	127	129	128
-----	0.20	234	235	237	236
-----	0.30	342	335	344	340
	Mean	235	232	237	235

Table 5: Mean rate of hen-day egg production (%) from the 28th to the 56th day by second-cycle hens fed the test diets

% Nonphytate Phosphorus	% Added Sodium	Sodium source				
		None[1]	Sodium Chloride	Sodium Bicarbonate	Sodium Sulfate	Mean
	0	2.90	----	----	----	----
0.25	0.10	----	84.64	77.85	76.83	79.78
0.25	0.20	----	85.36	81.56	72.14	79.69
0.25	0.30	----	76.60	76.65	84.31	79.19
	Mean		82.20^{x}	78.69^{xyz}	77.76^{yz}	79.55^{ab}
	1.61	----	----	----	----	
0.45	0.10	----	73.75	81.78	81.96	79.16
0.45	0.20	----	85.71	79.46	81.84	82.34
0.45	0.30	----	74.19	82.81	82.85	79.96
	Mean		77.88^{yz}	81.35^{xy}	82.22^{x}	80.49^{a}
		2.68	----	-----	----	-----
0.65	0.10	----	77.72	77.32	82.50	79.18
0.65	0.20	----	78.92	78.75	75.54	77.74
0.65	0.30	----	81.83	73.98	72.91	76.24
	Mean		79.49^{xyz}	76.68^{z}	76.98^{z}	77.72^{b}
Mean	0.10		78.70^{f}	78.99^{ef}	80.42^{ef}	79.37
Mean	0.20		83.33^{e}	79.93^{ef}	76.51f	79.92
Mean	0.30		77.54^{f}	77.81f	80.03^{ef}	79.25
	Mean		79.86	78.90	78.98	79.25

[1]Not included in the statistical analysis.

ab, ef, xyz Within comparisons, means with the same superscript do not differ significantly ($P \leq 0.05$)

significant effect on mean egg weight from 28 to 56 d on test (Table 6). There were no significant effects of NPP level, source or level of sodium, or any interaction among these main effects.

Breaking force: Mean breaking force of eggs produced from 28 to 56 d on test is shown in Table 7. Eggs from hens fed diets with 0.25 and 0.45% NPP did not differ significantly in breaking force, and were significantly higher than those from hens fed diets with 0.65% NPP There was no effect of sodium level on breaking force; however, there was an interaction between sodium source and sodium level (Fig. 3). When diets contained 0.1 or 0.2% added sodium the breaking force was

Table 6: Mean daily feed intake (g/day) from the 28th to the 56th day by second-cycle hens fed the test diets

% Nonphytate Phosphorus	% Added Sodium	Sodium source				Mean
		None[1]	Sodium Chloride	Sodium Bicarbonate	Sodium Sulfate	
	0	42.17	----	-----	-----	----
0.25	0.10	----	108.45	104.19	106.19	106.24
0.25	0.20	----	106.25	107.43	107.01	107.03
0.25	0.30	----	104.25	104.69	110.46	106.47
	Mean	----	106.45	105.44	107.85	106.58[b]
	0	42.25	----	-----	-----	----
0.45	0.10	----	105.55	112.92	107.63	108.70
0.45	0.20	----	111.97	107.83	112.09	110.63
0.45	0.30	----	108.46	110.70	111.42	110.20
	Mean		108.66	110.49	110.38	109.84[a]
	0	48.95	-----	-----	-----	------
0.65	0.10	----	108.22	101.19	109.11	106.18
0.65	0.20	----	101.11	105.45	103.98	103.52
0.65	0.30	-----	107.46	99.04	100.70	102.40
	Mean		105.60	101.90	104.60	104.03[b]
Mean	0.10	----	107.41	106.10	107.61	107.04
Mean	0.20	----	106.58	106.90	107.69	107.06
Mean	0.30	----	106.73	104.82	107.53	106.35
	Mean		106.90	105.94	107.61	106.82

[1]Not included in the statistical analysis. [ab]Within comparisons, means with the same superscript do not differ significantly ($P \leq 0.05$).

Table 7: Mean egg weight (g) from the 28th to the 56th day by second-cycle hens fed the test diets

% Nonphytate Phosphorus	% Added Sodium	Sodium source				Mean
		None[1]	Sodium Chloride	Sodium Bicarbonate	Sodium Sulfate	
	0	50.25	------	-----	-----	-----
0.25	0.10	-----	59.34	58.33	59.41	59.03
0.25	0.20	----	59.53	59.07	58.95	59.18
0.25	0.30	----	59.84	59.41	60.27	59.84
	Mean	-----	59.57	58.94	59.54	59.35
	0	53.50	-----	-----	-----	----
0.45	0.10	-----	58.30	60.29	57.75	58.78
0.45	0.20	-----	59.74	59.20	58.91	59.28
0.45	0.30	-----	59.38	60.11	58.01	59.17
	Mean	-----	59.14	59.87	58.23	59.08
	0	45.75	-----	-----	-----	----
0.65	0.10	-----	58.87	58.35	59.01	58.74
0.65	0.20	-----	59.17	59.99	58.16	59.10
0.65	0.30	-----	59.47	59.29	58.85	59.20
	Mean	-----	59.16	59.21	58.67	59.02
Mean	0.10	-----	58.84	58.99	58.72	58.85
Mean	0.20	------	59.48	59.42	58.68	59.19
Mean	0.30	-----	59.56	59.60	59.04	59.40
	Mean	-----	59.25	59.34	58.82	59.15

[1]Not included in the statistical analysis.

similar among hens fed the various sources of sodium; however when diets contained 0.3% added sodium the breaking force of eggs from hens fed sodium from sodium sulfate was highest while that of eggs from hens fed sodium bicarbonate was the lowest among the three sources. There were no interactions among or between level of NPP and level and source of sodium.

Shell deformation time: Shell deformation has often been proposed as a non-destructive measure of shell

Table 8: Mean breaking strength (g) of eggs produced from the 28th to the 56th day by second-cycle hens fed the test diets

% Nonphytate Phosphorus	% Added Sodium	Sodium source				Mean
		None[1]	Sodium Chloride	Sodium Bicarbonate	Sodium Sulfate	
0.25	0	2285	------	-------	------	-----
0.25	0.10	-----	3602	3578	3679	3619
0.25	0.20	-----	3579	3597	3478	3550
0.25	0.30	-----	3574	3466	3573	3538
	Mean	-----	3585	3547	3575	3569[x]
0.45	0	2990	-----	-----	-----	-----
0.45	0.10	-----	3427	3608	3441	3492
0.45	0.20	-----	3583	3503	3568	3551
0.45	0.30	-----	3645	3235	3688	3523
	Mean	----	3551	3449	3566	3522[x]
0.65	0	2315	-----	-----	----	----
0.65	0.10	----	3356	3467	3519	3447
0.65	0.20	-----	3454	3469	3327	3417
0.65	0.30	----	3346	3466	3635	3482
	Mean	-----	3385	3467	3494	3488[y]
Mean	0.10	----	3462[bc]	3551[ab]	3546[ab]	3519
Mean	0.20	-----	3538[ab]	3523[ab]	3456[bc]	3506
Mean	0.30	-----	3522[ab]	3389[c]	3632[a]	3515
	Mean	-----	3507	3488	3545	3513

[1]Not included in the statistical analysis. [abc, xy] Within comparisons, means with the same superscript do not differ significantly ($P \leq 0.05$)

strength (Potts and Washburn, 1974; Voisey and Hamilton, 1977; Halaj and Grofik, 1994). The test instrument used in the present studies (Voisey and McDonald, 1978) measures deformation as the seconds needed to apply from 100 to 1100 g of force. Mean deformation time of eggs from hens in the present study are shown in Table 9. Increasing the dietary phosphorus resulted in significantly increasing the deformation time, indicating an egg shell with more rigidity. Increasing the overall level of sodium in the diet also resulted in a significant increase in deformation time, with no interaction among or between sodium level, sodium source, and phosphorus content of the diet.

Discussion

The adverse effects of high dietary phosphorus levels on rate of egg production have been noted by several workers (Harms *et al*., 1965; Charles and Jensen, 1975). It has been reported by a number of workers that high levels of phosphorus reduce shell thickness or breaking strength (Arscott *et al*., 1962; Taylor, 1965; Mostert and Swart, 1968; Hunt and Chancey, 1970; Damron *et al*., 1974; Summers *et al*., 1976; Scott *et al*., 1976; Hamilton and Sibbald, 1977; Holder, 1981; Härtel, 1989; Vandepopuliere and Lyons, 1992; Hossain and Bertechini, 1998; Borrmann *et al*., 2001). Results of the present study support that of previous workers in this respect.

Few studies have specifically addressed the phosphorus needs of second-cycle laying hens. Holder (1981) stated that a total P level greater than 0.5% (approximately 0.25% nonphytate P) was needed for egg production and egg shell quality in force-molted hens. Borrmann *et al.* (2001) reported that the best egg shell quality in second cycle layers was obtained when the diet contained 0.29% available P in diets without phytase or 0.26% with phytase. Bar *et al.* (2002) noted that a dietary P content of 0.45% total P with 0.10% added inorganic P was sufficient for maintaining egg production and shell quality in aged laying hens given 3.6 to 4.0% Ca. Soní-Guillermo *et al*. (2004) evaluated needs for P in different stages of second-cycle hens and reported that the biological optimum levels for maximum egg production and specific gravity were 0.38 and 0.28% nonphytate P, respectively. Snow *et al*. (2004) reported that molted hens in their second cycle had a requirement for P greater than 0.20% available P or 209 mg available P per day. Unfortunately the next increment of P tested in this study was 0.40% available P making it difficult to provide a closer estimate of P needs. Results of the present study indicate that no more than 266 mg/day of nonphytate P was sufficient for maximum egg production and shell quality of second-cycle hens, in agreement with the 250 mg/day suggested by NRC (1994).

The response of laying hens to dietary supplementation with sodium bicarbonate has been highly variable.

Table 9: Mean deformation time (seconds needed to apply from 100 to 1100 g of force) of eggs collected from the 28th to the 56th day from second-cycle hens fed the test diets

% Nonphytate Phosphorus	% Added Sodium	Sodium source: None[1]	Sodium Chloride	Sodium Bicarbonate	Sodium Sulfate	Mean
0.25	0	0.1632	------	-------	-------	-----
0.25	0.10	----	0.1992	0.1983	0.1969	0.1982
0.25	0.20	----	0.2011	0.1985	0.2031	0.2009
0.25	0.30	----	0.1983	0.2062	0.2014	0.2020
	Mean		0.1995	0.2010	0.2005	0.2004[b]
0.45	0	0.1757	-----	-------	-----	------
0.45	0.10	------	0.2020	0.1962	0.2036	0.2006
0.45	0.20	-----	0.2026	0.2048	0.1985	0.2020
0.45	0.30	-----	0.2005	0.2108	0.1975	0.2030
	Mean	------	0.2017	0.2040	0.1999	0.2018[ab]
0.65	0	0.2682	-----	------	-----	-----
0.65	0.10	------	0.2047	0.1989	0.1981	0.2006
0.65	0.20	-----	0.2068	0.2044	0.2042	0.2051
0.65	0.30	-----	0.2160	0.2064	0.2026	0.2084
	Mean	-----	0.2092	0.2033	0.2017	0.2047[a]
Mean	0.10		0.2020	0.1978	0.1996	0.1998[y]
Mean	0.20		0.2035	0.2026	0.2020	0.2027[xy]
Mean	0.30		0.2050	0.2078	0.2006	0.2045[x]
	Mean		0.2035	0.2028	0.2007	0.2023

[1]Not included in the statistical analysis. [ab,xy] Within comparisons, means with the same superscript do not differ significantly ($P \leq 0.05$).

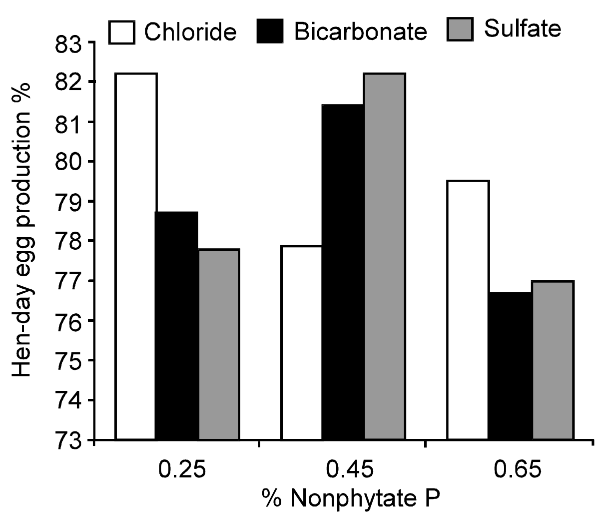

Fig. 1: Interaction of sodium source and nonphytate P level on hen-day egg production

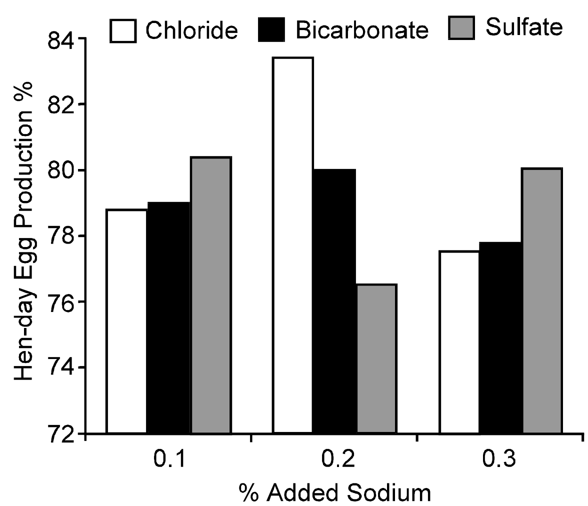

Fig. 2: Interaction of sodium source and sodium level on hen-day egg production

Some have reported positive results (Frank and Burger, 1965; Howes, 1966; Makled and Charles, 1987), some 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) while others have reported variable responses (Harms and Miles, 1980; Latif and Quisenberry, 1968). These studies have varied widely in terms of heat stress, lighting conditions, and many other factors that might influence response to sodium bicarbonate. In contrast to the present research in which the various sources of sodium were used to provide the specific dietary Na levels evaluated, in many of the reported studies sodium bicarbonate was added to diets already considered adequate in sodium, thus increasing total dietary sodium levels. Choi and Han (1983) added 0.55% Na from both sodium chloride and sodium bicarbonate to a diet containing 0.35% NaCl. The high level of sodium

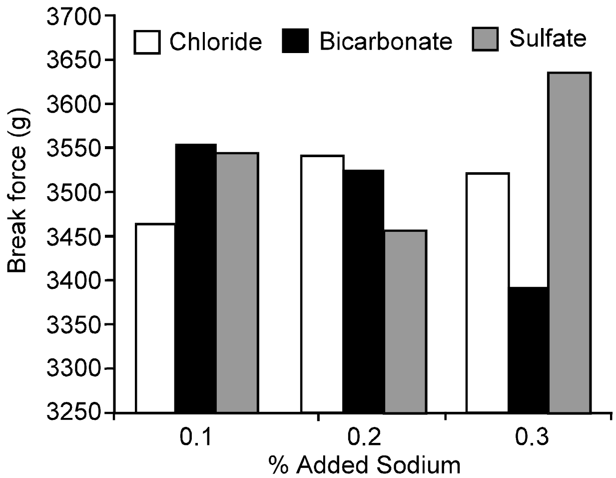

Fig. 3: Interaction of sodium source and sodium level on egg shell breaking force

from either source decreased egg production when the diets contained a low level of phosphorus, and increased egg production when the diets contained a high level of phosphorus, in agreement with the previous reports of Choi *et al*. (1980) and Junqueira *et al*. (1984). No significant effects on egg shell quality were observed due to sodium source. Makled and Charles (1987) added 0.5% sodium bicarbonate to complete layer diets and reported that addition of the bicarbonate significantly improved the elasticity of the egg shell. Balnave and Muheereza (1997) reported that the addition of 1% sodium bicarbonate to a diet already containing sodium chloride resulted in improvements in egg shell breaking strength in end-of-lay hens maintained on continuous light in temperatures of 30 and 35°C. Thus, it may be possible that a portion of the reported response to sodium bicarbonate may be due at least in part to increased dietary sodium levels that may be offsetting some of the negative response to higher dietary phosphorus levels.

Results of the present study provide information regarding sodium and phosphorus needs of second-cycle hens. These appear to be in concert with requirements suggested by the NRC (1994). No response to sodium bicarbonate above that observed with sodium chloride or sodium sulfate was noted in the present study, which was not conducted under heat stress conditions. All sodium sources were used to provide the same levels of sodium, in contrast to many studies where the bicarbonate was added in addition to that in the normal diet. This deserves further study as a possible explanation for observed improvements in shell characteristics from addition of sodium bicarbonate.

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