Eggshell Quality as Influenced by Sodium Bicarbonate, Calcium Source, and Photoperiod[1]

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ABSTRACT The effects of Ca source (limestone or a mixture of one-third limestone and two-thirds oyster shell), $NaHCO_3$ (0 or .5%) and feeding photoperiod (16 or 24 hr) were studied in a 16-week experiment involving 240 Hy-Line W-36 Leghorn hens, 25 weeks of age. Neither egg production (percent hen-day and egg mass, kg egg/bird per 16 weeks) nor feed conversion ratio (kg feed per kg egg) were significantly ($P>.05$) affected by dietary treatment or photoperiod. However, extending the photoperiod to 24 hr significantly ($P<.05$) increased feed consumption with a consequent increase in egg weight ($P<.01$).

Feeding oyster shell in combination with limestone significantly ($P<.05$) improved specific gravity of eggs, whereas dietary $NaHCO_3$ significantly ($P<.01$) improved elasticity of the egg shell as measured by deformation. Eggshell quality was improved by increasing the photoperiod to 24 hr and was most pronounced when hens were fed diets supplemented with .5% $NaHCO_3$ and limestone as the only source of Ca.

(*Key words:* eggshell quality, calcium source, sodium bicarbonate, metabolic alkalosis, acid base balance)

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INTRODUCTION

The addition of dietary $NaHCO_3$ as a means of improving eggshell quality has been investigated extensively (Frank and Burger, 1965; Howes, 1966; Mongin, 1968; Pepper *et al.*, 1968; Charles *et al., 1972; Cohen et al.*, 1972; Hamilton, 1981; and Odiba *et al.*, 1981). Many hens lay relatively early in the morning. Since most of the Ca is laid down during the last 6 to 8 hr of egg formation, very little dietary Ca remains in the digestive tract during Ca deposition. Despite the tendency of the hen to adjust Ca intake and storage to its requirement, the hen may still have problems obtaining sufficient Ca for eggshell formation during early morning hours (Tyler, 1955; Scott *et al.*, 1971; Roland, 1973). Scott *et al.*, 1971; Charles *et al.*, 1972; and Charles and Duke, 1981 suggest that an increased particle size of dietary Ca may reduce labile Ca turnover, thus contributing to an improved eggshell quality. These researchers report that the replacement of finely ground limestone with hen-sized oyster shell resulted in a metering of Ca into the digestive tract, thereby providing a source of Ca during the night. This hypothesis has been used to explain the improvement in eggshell quality when oyster shell replaces finely ground limestone (Scott *et al.*, 1971). However, Muir *et al.* (1976) and Roland (1981) concluded that particle size had no effect on shell quality if the diet contained sufficient Ca.

Mongin (1978) reported that two hydrogen ions are generated for each molecule of $CaCO_3$ synthesized in the shell gland, resulting in an acidosis increase until the 22nd hr after ovulation (Mongin, 1970). We postulate that the laying hen needs a source of alkaline material to compensate metabolic acidosis as well as a source of Ca during eggshell calcification at night. Therefore, the objective of this study was to test the possibility that a continuous provision of Ca with $NaHCO_3$ under a continuous access to feed regimen (24 hr light) may lead to an improvement in eggshell quality.

MATERIALS AND METHODS

Two hundred and forty Hy-Line W-36 Leghorn hens, 25 weeks of age, of approximately equal weight and production rate (80%) were assigned to 20 cm × 45 cm wire cages at

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the density of two hens per cage. Cage assignments were based on a 2 × 2 × 2 factorial arrangement of treatments. Eight treatment groups (three random replicates of five cages each) provided for two levels of sodium bicarbonate (0 or .5%), two sources of dietary calcium (ground limestone only or one-third limestone and two-thirds oyster shell) and two photoperiods (either 16 or 24 hr).

The experimental period (16 weeks) extended from June 21 through October 10, 1984. During this time, inside temperature was recorded twice daily (at 800 and 1500 hr). Average daily temperature ranged from 27.8 C during the first 28-day period to 24.3 C during the fourth 28-day period, with a maximum of 32.9 C and a minimum of 15.6 C.

At the end of each 28-day period the productive response was determined. These measurements included egg production, as measured by hen-day percent and egg mass in kilogram of egg per bird, feed consumption, and feed conversion ratio (kilogram feed per kilogram egg). Exterior shell quality evaluations were based on specific gravity (by saline solution), Marius deformation, and Instron breaking strength. These evaluations, along with egg weighing, were conducted on each individual egg produced on the 26th, 27th, and 28th day of each 28-day period. During the same three-day period, 15 eggs from each treatment group were broken to determine shell weight, shell percent, shell weight per unit of shell surface (milligrams per square centimeter) (Carter, 1975), albumen height (Haugh

TABLE 1. *Composition and nutrient level of the experimental diets*

Composition	Diet number[1] 1 (basal)	2	3	4
	(%)			
Ingredients				
Ground yellow corn	62.74	62.74	62.24	62.24
Soybean meal	21.27	21.27	21.27	21.27
Limestone	7.58	2.53	7.58	2.53
Oyster shell	0	5.05	0	5.05
Meat and bone scraps	4.00	4.00	4.00	4.00
Wheat middlings	2.40	2.40	2.40	2.40
Defluorinated phosphate	1.20	1.20	1.20	1.20
Salt	.35	.35	.35	.35
Egg layer premix[2]	.25	.25	.25	.25
Methionine DL-98	.16	.16	.16	.16
Trace minerals mix[3]	.05	.05	.05	.05
$NaHCO_3$	0	0	.50	.50
Nutrients[4]				
Metabolizable energy kcal/kg	2,816	2,816	2,798	2,798
Crude protein, %	18.00	18.00	17.96	17.96
Calcium, %	3.77	3.79	3.69	3.71
Total P, %	.68	.69	.69	.69
Na, %	.23	.25	.35	.36
K, %	.67	.66	.67	.68
Cl, %	.30	.29	.30	.30
Na+K−Cl, meq/kg	187	196	239	246

[1] Treatments 1 and 2 were fed Diet 1; Treatments 3 and 4 were fed Diet 2; Treatments 5 and 6 were fed Diet 3; and Treatments 7 and 8 were fed Diet 4.

[2] Layer premix formulated to provide per kilogram diet: 4,400 IU vitamin A; 1,650 IU vitamin D; 6.6 IU vitamin E; 7 μg vitamin B_{12}; 6.6 mg Riboflavin; 9.9 mg d-pantothenic acid; 1.65 mg vitamin K (menadione dimethylpyrimidinol bisulfite).

[3] Trace mineral premix formulated to provide the following levels (mg/kg diet): Mn, 59; Zn, 49; Fe, 29; Cu, 5; I, 1.

[4] Metabolizable energy and protein calculated; calcium, total phosphorus, sodium, potassium, and chlorine were determined analytically.

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units), and yolk color (by Roche fan).

Experimental diets were based on nutrient levels used in commercial practice. Prior to feeding, laboratory assays (Association of Official Analytical Chemists, 1980) were conducted on each ration for Ca, total P, Na, K, and Cl. Using these laboratory determined values, $NaHCO_3$ levels were adjusted to provide monovalent cation-anion relationships (Na + K–Cl) expressed as milliequivalents per kilogram. The Na + K–Cl ratio of diets without $NaHCO_3$ was less than 200 and was increased to 239 and 246, respectively, for two diets containing .5% $NaHCO_3$ (Table 1). Analyses of the drinking water revealed very low levels of Na, K, and Cl. Therefore, the contributions of these elements via the drinking water were not considered in the calculations.

Data from the entire experimental period (16 weeks) were pooled and analyzed by analysis of variance using the Statistical Analysis System (Statistical Analysis System, 1979); source of Ca, level of $NaHCO_3$, and photoperiod were considered fixed effects. Differences between treatment means and also between main treatment categories were tested according to Tukey (1949).

RESULTS AND DISCUSSION

Egg production, as measured by hen-day percent, and egg mass (kilogram of egg per bird per 16 weeks) were not significantly ($P>.05$) affected by either Ca source, $NaHCO_3$, or photoperiod. However, there was a significant ($P<.01$) interaction (percent hen-day production) between the level of $NaHCO_3$ and the photoperiod (Table 2). The interaction signifies an increase in percent hen-day production for the 16 hr photoperiod in the absence of $NaHCO_3$ only: the average of Groups 1 and 3 was 88.37% *vs.* 86.35% for Groups 2 and 4.

Feed consumption was significantly ($P<.05$) greater when the photoperiod was 24 hr (Table 2). This effect was more pronounced when lime-

TABLE 2. *Main effects of source of Ca, level of $NaHCO_3$, and photoperiod on productive performance, feed consumption, and feed conversion ratio*

	Egg production			
	Hen-day	16-wk Egg mass	Feed consumption	Feed conversion ratio
	(%)	(kg egg/bird)	(g/bird)	(kg feed/kg egg)
Main effects				
Source of Ca[1]	NS[2]	NS	NS	NS
LS	87.26	5.439	99.81	2.069
LS + OS	87.36	5.466	100.51	2.062
Level of $NaHCO_3$	NS	NS	NS	NS
0%	87.36	5.447	100.23	2.049
.5%	87.26	5.458	100.09	2.082
Photoperiod (PP)	NS	NS	*	NS
16 hr	87.56	5.434	98.90	2.059
24 hr	87.06	5.471	101.42	2.072
Interactions				
Ca × $NaHCO_3$	NS	NS	NS	NS
Ca × PP	NS	NS	*	NS
$NaHCO_3$ × PP	**	NS	NS	NS
Ca × $NaHCO_3$ × PP	NS	NS	NS	NS
SE[3]	.397	.078	.73	.021
(df)	376	16	376	88

[1] LS = Limestone; LS + OS = 1/3 limestone + 2/3 oyster shell.

[2] NS = No significant difference ($P>.05$).

[3] SE = Standard error of the mean.

*$P<.05$.

**$P<.01$.

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stone was the only source of Ca in the diet (Table 3). Feed consumption of the laying hen may be sensitive to both source and level of Ca. Moran *et al.* (1970) reported a reduction in feed intake when a 3% Ca diet, supplemented with oyster shell, was fed compared with feeding a 3% Ca diet without oyster shell. In contrast, Scott *et al.* (1971) found that replacing two-thirds of limestone in a laying hen diet with oyster shell produced an increase in feed intake. Ca intake can be influenced by many factors, depending on dietary Ca level and production rate of the hen (Roland, 1985). For example, if dietary Ca exceeds the hen's nutrient requirement without reducing palatability, a reduction in energy consumption will result. As hens eat to meet energy requirements (Scott *et al.*, 1982), overconsumption may occur. However, a Ca level sufficiently high to influence palatability may result in a decline in consumption (Roland, 1985).

Under some circumstances, dietary Ca may be sufficiently marginal so that shell quality is reduced but production is maintained. The hen may then overconsume energy in an attempt to meet Ca requirements (Scott *et al.*, 1971; Lennards and Roland, 1981; and Roland, 1985). In this study, Ca level did not appear to be a primary problem. Increased feed intake occurred with continuous lighting. Increased feed consumption was accompanied by a correspondingly significant ($P<.01$) increase in egg weight (Table 4). However, nonsignificant differences in feed conversion ratio (kilogram feed per kilogram egg) were observed (Table 2).

Effects of dietary Ca source, $NaHCO_3$ level, and photoperiod on eggshell quality (Tables 4 and 5) suggest that the substitution of oyster shell for two-thirds of the ground limestone significantly ($P<.05$) improved eggshell quality when measured by specific gravity (Table 4). The inclusion of .5% $NaHCO_3$ significantly ($P<.01$) improved eggshell elasticity as measured by Marius deformation. More important, however, both photoperiod and the interaction between source of Ca and level of $NaHCO_3$ appear to have a more pronounced effect on eggshell quality (Table 4).

In the absence of $NaHCO_3$, specific gravity and Marius deformation were significantly ($P<.05$) improved when the photoperiod was increased from 16 to 24 hr (Table 5). Breaking strength, shell weight, shell percent, and shell weight per unit of surface area were also improved by increasing the photoperiod when limestone was provided as the only source of

TABLE 3. *Effect of $NaHCO_3$, Ca source and photoperiod on productive performance, feed consumption, and feed conversion ratio in Treatments 1–8*[1]

	Sodium bicarbonate (0%)				Sodium bicarbonate (.5%)			
	LS[3]		LS + OS[3]		LS		LS + OS	
Variables[2]	16 hr	24 hr	16 hr	24 hr	16 hr	24 hr	16 hr	24 hr
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Egg production Percent hen-day	88.33 ± 4.20	85.80 ± 5.36	88.40 ± 4.34	86.90 ± 5.06	86.63 ± 6.79	88.28 ± 5.69	86.86 ± 7.14	87.26 ± 4.61
16-wk Egg mass (kg egg/bird)	5.415 ± .154	5.430 ± .298	5.479 ± .170	5.463 ± .147	5.326 ± .367	5.584 ± .124	5.517 ± .258	5.406 ± .091
Feed consumption, (g/bird per day)	98.0 ± 8.7	101.6 ± 8.8	100.7 ± 11.0	100.7 ± 9.8	97.1 ± 10.9	103.0 ± 8.3	100.2 ± 14.6	100.7 ± 8.8
Feed conversion ratio, (kg diet: kg egg)	2.026 ± .079	2.084 ± .172	2.061 ± .132	2.025 ± .149	2.083 ± .142	2.083 ± .135	2.067 ± .189	2.094 ± .116

[1]Mean ± standard deviation.

[2]There were no significant differences among means within variables.

[3]LS = Limestone, LS + OS = 1/3 limestone + 2/3 oyster shell.

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TABLE 4. *Main effects of source of Ca, level of* $NaHCO_3$, and photoperiod on eggshell quality, Haugh units, and yolk color

	Egg weight	Specific gravity	Deformation	Breaking strength	Shell weight	Shell percent	SWUSA[1]	Haugh units	Yolk color
	(g)				(g)		(mg/cm^2)		
Main effects									
Source of Ca[2]	NS[3]	*	NS	NS	NS	NS	NS	**	*
LS	55.541	1.0865	27.11	5.59	5.650	10.08	82.85	79.03	8.01
LS + OS	55.611	1.0870	26.80	5.64	5.686	10.11	83.22	77.11	8.21
Level of $NaHCO_3$	NS	NS	**	NS	NS	NS	NS	NS	**
0%	55.604	1.0866	27.30	5.60	5.694	10.09	83.13	78.31	7.73
.5%	55.548	1.0869	26.60	5.63	5.642	10.10	82.94	77.84	8.48
Photoperiod (PP)	**	**	**	**	**	**	**	**	NS
16 hr	55.140	1.0859	27.55	5.51	5.598	9.99	82.11	79.24	8.13
24 hr	56.014	1.0875	26.36	5.72	5.738	10.20	83.96	76.91	8.09
Interactions									
Ca × $NaHCO_3$	NS	**	**	**	**	**	**	NS	**
Ca × PP	**	NS	*	**	NS	NS	NS	NS	NS
$NaHCO_3$ × PP	NS	NS	NS	NS	NS	NS	NS	**	NS
Ca × $NaHCO_3$ × PP	NS	NS	NS	NS	NS	NS	NS	NS	NS
SE[4]	.144	.00014	.11	.022	.029	.05	.38	.44	.06
(df)	2,450	2,428	2,402	2,370	472	472	472	472	471

[1] SWUSA = Shell weight per unit surface area.

[2] LS = Limestone; LS + OS = one-third limestone + two-thirds oyster shell.

[3] NS = No significant difference ($P>.05$).

[4] SEM = Standard error of the mean.

*$P<.05$.

**$P<.01$.

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TABLE 5. *Effect of sodium bicarbonate, calcium source, and photoperiod on eggshell quality, Haugh units, and yolk pigmentation in treatments 1 to 8*[1]

Variables	Sodium bicarbonate (0%)				Sodium bicarbonate (.5%)			
	LS[2]		LS + OS[2]		LS		LS + OS	
	16 hr	24 hr	16 hr	24 hr	16 hr	24 hr	16 hr	24 hr
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Egg weight, g	54.68 ± 4.51^{b}	56.47 ± 5.33^{a}	55.29 ± 4.71^{a}	56.03 ± 5.00^{a}	54.69 ± 4.74^{b}	56.35 ± 4.30^{a}	55.91 ± 5.43^{a}	55.24 ± 6.01^{a}
Specific gravity	1.0848 ± .0053^{c}	1.0868 ± .0046^{b}	1.0865 ± .0048^{b}	1.0883 ± .0048^{a}	1.0864 ± .0053^{b}	1.0881 ± .0045^{a}	1.0860 ± .0049^{b}	1.0871 ± .0046^{b}
Marius deformation	28.60 ± 4.31^{a}	27.43 ± 3.79^{b}	27.01 ± 3.99^{b}	26.10 ± 3.68^{c}	27.15 ± 4.43^{b}	25.16 ± 3.78^{d}	27.38 ± 3.64^{b}	26.73 ± 3.74^{b}
Instron breaking strength	5.27 ± .77^{c}	5.67 ± .80^{a}	5.70 ± .80^{a}	5.79 ± .78^{a}	5.59 ± .76^{b}	5.85 ± .78^{a}	5.50 ± .74^{b}	5.58 ± .74^{b}
Shell weight, g	5.482 ± .466^{b}	5.733 ± .462^{a}	5.709 ± .522^{a}	5.853 ± .451^{a}	5.643 ± .480^{a}	5.743 ± .394^{a}	5.559 ± .380^{a}	5.623 ± .427^{a}
Shell percent	9.81 ± .83^{b}	10.14 ± .80^{a}	10.12 ± .81^{a}	10.29 ± .74^{a}	10.13 ± .85^{a}	10.23 ± .69^{a}	9.89 ± .73^{b}	10.15 ± .77^{a}
SWUSA[3] (mg/cm^2)	80.64 ± 6.52^{b}	83.55 ± 5.81^{a}	83.34 ± 6.41^{a}	84.99 ± 5.75^{a}	83.08 ± 6.37^{a}	84.12 ± 5.00^{a}	81.37 ± 5.37^{b}	83.19 ± 5.84^{a}
Haugh units	79.8 ± 6.9^{a}	78.4 ± 7.9^{a}	77.1 ± 7.0^{a}	78.0 ± 6.7^{a}	81.2 ± 7.0^{a}	76.8 ± 7.0^{a}	78.9 ± 5.1^{a}	74.5 ± 6.4^{b}
Yolk color	7.46 ± .92^{c}	7.53 ± 1.11^{c}	8.00 ± .84^{b}	7.93 ± .92^{b}	8.55 ± .91^{a}	8.48 ± 1.13^{a}	8.50 ± 1.03^{a}	8.40 ± 1.11^{a}

[a–d]Means within rows with different superscripts are significantly different (P>.05).

[1]Mean ± standard deviation.

[2]LS = Limestone; LS + OS = one-third limestone plus two-third oyster shell.

[3]SWUSA = Shell weight per unit of surface area.

Ca. When oyster shell was included in the ration, a nonsignificant (P>.05) increase occurred (in the parameters described) with increasing photoperiod. When $NaHCO_3$ was included in diets containing no oyster shell, increasing the photoperiod resulted in a significant improvement in eggshell quality as measured by specific gravity, deformation, and breaking strength. By adding oyster shell as a Ca source, increasing the photoperiod caused significant improvements (P<.05) in shell percent and shell weight per unit surface area, but only nonsignificant improvements in specific gravity, deformation, breaking strength, and shell weight.

Several investigators reported greater shell thickness or shell strength if part of the dietary Na was provided as $NaHCO_3$ rather than as NaCl (Frank and Burger, 1965; Howes, 1966; and Vogt, 1974). Other workers were unable to demonstrate these beneficial effects (Pepper *et al.*, 1968; Cox and Balloun, 1968; Ernst *et al.*, 1975; Odiba *et al.*, 1981). Mongin (1980) reported that significant improvements in shell quality were detected in most cases where the additions of $NaHCO_3$ increased the dietary Na+K–Cl values from 160 to 180 to 200 or more meq per kilogram of diet. In this study, the significant improvement in shell elasticity (deformation) may be caused by similar changes in the acid base values of the experimental diets since $NaHCO_3$ supplementation resulted in an increase from 187 meq/kg to 246 meq/kg in Na+K–Cl values.

Scott *et al.* (1971) reported that oyster shell particles accumulated in the gizzard during the day and dissolved slowly throughout the night, thus maintaining elevated blood Ca levels during nonfeeding periods. Different aspects of shell quality were reported to be improved by partial replacement of limestone with oyster shell in the diet (Moran *et al.*, 1970; Scott *et al.*, 1971; Brister *et al.*, 1981); Charles and Duke, 1981 and Hamilton *et al.*, 1985). Additional support is provided by the results of this study. In the absence of $NaHCO_3$, shell quality was significantly improved (P<.05) by oyster shell additions (one-third limestone, two-thirds oyster shell) when photoperiod was restricted to 16 hr (Table 5). When the photoperiod was increased from 16 to 24 hr, improvements in shell quality equal to those produced by feeding dietary oyster shell resulted, as measured by specific gravity, Marius deformation, breaking strength, shell weight, shell percent, and shell weight per unit of shell surface (Table 5). In contrast, Roland

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(1981) reported that the inclusion of pullet- size oyster shell in the diet of laying hens will give a positive response in eggshell quality only if hens are consuming inadequate Ca. However, Lennards and Roland (1981) found that time of Ca intake was important in determining hens' ability to calcify eggshells.

We postulated that laying hens may need a source of alkaline material to buffer hydrogen ions resulting from nighttime shell calcification. Our findings suggest that under the conditions of this experiment, a significant improvement in eggshell quality may be achieved through increasing the photoperiod to 24 hr. Our results also suggest that the presence of $NaHCO_3$ together with limestone in the digestive system at the time of shell calcification enhances the effect of $NaHCO_3$ supplementation. Miles (1982) reported that the addition of dietary $NaHCO_3$ improved shell quality of those eggs laid in the afternoon. He suggested that the response was due to a change in the $NaHCO_3$ levels in the digestive system during the egg-laying cycle.

Interior egg quality, as measured by Haugh units and yolk color, was influenced by dietary treatments (Tables 4 and 5). Haugh units were significantly higher ($P<.01$) when limestone was provided as the only Ca source and the photoperiod was restricted to 16 hr (Table 4). These findings are similar to those of Hamilton *et al.*, (1985) who reported lower Haugh units from eggs when hens were provided oyster shell. A significant increase ($P<.01$) in yolk pigmentation when dietary $NaHCO_3$ was provided (Tables 4 and 5) is similar to the findings of Bushong *et al.* (1972), but contrary to those of Ernst and Hendershott (1977).

In conclusion, these data suggest that over a 16-week feeding period, increasing the Na + K–Cl value of the laying hen diet to approximately 240 meq/kg by $NaHCO_3$ supplementation in combination with limestone and a 24-hr photoperiod may result in improved eggshell quality.

REFERENCES

Association of Official Analytical Chemists, 1980. Official Methods of Analysis. 13th ed. Assoc. Offic. Anal. Chem., Washington, DC.

Brister, R. D., Jr., S. S. Linton, and C. R. Creger, 1981. Effects of dietary calcium sources and particle size on laying hen performance. Poultry Sci. 60:2648–2654.

Bushong, R. D., Jr., B. C. Dilworth, and E. J. Day, 1972. The influence of ethoxyquin and sodium bicarbonate on egg yolk pigmentation. Poultry Sci. 51:1768–1770.

Carter, T. C., 1975. The hen's egg: estimation of shell superficial area and egg volume, using measurements of fresh egg weight and shell length and breadth alone or in combination. Br. Poult. Sci. 16:541–543.

Charles, O. W., R. Clark, T. M. Huston, and J. V. Shutze, 1972. The effect of calcium source, sodium bicarbonate and temperature on eggshell quality. Poultry Sci. 51:1793. (Abstr.)

Charles, O. W., and S. Duke, 1981. Further studies on the use of various sources of calcium carbonate in laying hen diets. Univ. Ga. Ext. Poult. Sci. Dept., Publ. No. 240, Athens, GA.

Cohen, I., S. Hurwitz, and A. Bar, 1972. Acid-base balance and sodium to chloride ratio in diets of laying hens. J. Nutr. 102:1–8.

Cox, A. C., and S. L. Balloun, 1968. Lack of effect of sodium bicarbonate on shell characteristics. Poultry Sci. 47:1370–1371.

Ernst, R. A., F. R. Frank, F. C. Price, R. E. Burger, and H. R. Halloran, 1975. The effect of feeding low chloride diets with added sodium bicarbonate on eggshell quality and other economic traits. Poultry Sci. 54:270–274.

Ernst, R. A. and R. D. Hendershott, 1977. Effect of dietary sodium bicarbonate on eggshell quality. Poultry Sci. 56:1712. (Abstr.)

Frank, F. R., and R. E. Burger, 1965. The effect of carbon dioxide inhalation and sodium bicarbonate ingestion on eggshell deposition. Poultry Sci. 44:1604–1606.

Hamilton, R.M.G., 1981. The relationship between acid-base balance in the laying hen and eggshell strength. Pages 8–16 *in:* Georgia Nutr. Conf., Athens, GA.

Hamilton, R.M.G., R. W. Fairfull, and R. S. Gowe, 1985. Use of particulate limestone or oyster shell in the dietary regimen of White Leghorn hens. Poultry Sci. 64:1750–1762.

Howes, J. R., 1966. Eggshell quality as affected by the addition of bicarbonate to the feed and water. Poultry Sci. 45:1092. (Abstr.).

Lennards, R. M., and D. A. Roland, Sr., 1981. The influence of time of dietary calcium intake on shell quality. Poultry Sci. 60:2106–2113.

Miles, R. D., 1982. An update on eggshell quality. Pages 59–77 *in:* Proc. Florida Nutr. Conf., Gainesville, FL.

Mongin, P. E., 1968. Role of acid-base balance in the physiology of eggshell formation. World's Poult. Sci. J. 24:200–230.

Mongin, P., 1970. The role of the carbonate ion in eggshell formation. Pages 99–102 *in:* Proc. Cornell Nutr. Conf., Ithaca, NY.

Mongin, P., 1978. Acid-base balance during eggshell formation. Pages 247–259 *in:* Respiratory Function in Birds: Adult and Embryonic. J. Piiper, ed. Springer-Verlag, New York, NY.

Mongin, P., 1980. Roles of sodium, potassium and chloride in eggshell quality. Pages 213–223 *in:* Proc. Florida Nutrition Conf., Gainesville, FL.

Moran, E. T., Jr., A. Eyal, and J. D. Summers, 1970. Effectiveness of extra-dietary calcium supplements in improving eggshell quality and the influence of added phosphorus. Poultry Sci. 49:1011–1021.

Muir, F. V., P. C. Harris, and R. W. Gerry, 1976. The comparative value of five calcium sources for laying hens. Poultry Sci. 55:1046–1051.

Odiba, J. Y., M. L. Sunde, and H. R. Bird, 1981. The effects of dietary levels of chloride and bicarbonate on egg production and shell quality. Proc. Soc. Exp. Biol. and Med. 166:532–535.

Pepper, W. F., J. D. Summers, and J. D. McConachie,

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1968. The effect of high levels of calcium, fish products and sodium bicarbonate on eggshell quality. Poultry Sci. 47:224–229.

Roland, D. A., Sr., 1973. Calcium metabolism and the eggshell. Pages 109–119 *in:* Proc. Georgia Nutr. Conf., Athens, GA.

Roland, D. A., Sr., 1981. Calcium requirements of Leghorn hens. Feedstuffs. 53(7):18, 26–27.

Roland, D. A., Sr., 1985. Calcium and its relationship to excess feed consumption, body weight, egg size, fat deposition, shell quality and fatty liver hemorrhagic syndrome. Poultry Sci. 64:2341–2350.

Scott, M. L., S. J. Hull, and P. A. Mullenhoff, 1971. The calcium requirements of laying hens and effects of dietary oyster shell upon eggshell quality. Poultry Sci. 50:1055–1063.

Scott M. L., M. C. Nesheim, and R. J. Young, 1982. Nutrition of the Chicken. 3rd ed. M. L. Scott and Assoc., Ithaca, NY.

Statistical Analysis System, 1979. SAS User's Guide. SAS Inst., Inc., Raleigh, NC.

Tukey, J. W., 1949. Comparing individual means in the analysis of variance. Biometrics 36:99–114.

Tyler, C., 1955. The variations in limestone and flint grit consumption by laying hens. J. Sci. Food Agric. 6:696–704.

Vogt, H., 1974. Different chloride and sodium contents in laying rations. Arch. Geflegelkd. 38(3):77–81. [Chem. Abstr. 81(12), 150783 (1974).]

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