EFFECTS OF DIETARY CALCIUM SOURCES ON LAYING HEN PERFORMANCE

A Thesis

by

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ABSTRACT

Effects of Dietary Calcium Sources on
Laying Hen Performance. (August 1980).
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Two experiments were conducted with two different ages of commercial egg-type laying hens fed diets in which the calcium source, calcium level and combination of calcium sources varied in order to determine which source and combination produced the best egg shell quality.

The substitution of one-third of the supplemental calcium as large particle calcium carbonate in a complete laying hen diet was found to significantly improve egg shell quality. Percent egg production, feed conversion and egg weights were not significantly affected by the source or particle size of the supplemental calcium. The data indicates that the calcium from oyster shell is more available than that from limestone.

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DEDICATION

To my parents, Mr. and Mrs. Roy David Brister.

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INTRODUCTION

One of the greatest economic losses to the commercial egg producer results from poor egg shell quality. Approximately 10% of all eggs laid in a commercial layer operation never reach the consumer because of improper egg shell formation and egg breakage.

Various calcium sources have been examined for the availability of calcium to the hen for subsequent egg shell formation. Commonly utilized supplemental calcium sources for chickens and turkeys are limestone and oyster shell, in both pulverized and granulated form. Recently a new calcium source, Aragonite[1], in granular form, has become available to the commercial egg producer. Commercially available Aragonite is a screened granular calcium source from the ocean consisting primarily of sea shell particles.

This study is designed to determine the effects of various calcium sources of different particle size, fed in different combinations, on laying hen performance.

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[1]Aragonite - a mineral consisting of calcium carbonate and calcite of calcium carbonate but differing from calcite in its orthorhombic crystallization, greater density, and less distinct cleavage.

This paper follows the style of Poultry Science.

REVIEW OF LITERATURE

Scott *et al*. (1971), using 30 pullets per treatment, demonstrated that the substitution of 5% hen-sized oyster shell for 5% pulverized limestone, in a complete diet containing 3.5% total calcium, resulted in an improvement of egg shell strength over a nine-month period. However, the birds laid eggs at a much lower rate than commonly encountered under commercial conditions. These shell quality results are similar to those reported by Quisenberry and Walker (1970) who found that feeding oyster shell to laying hens produced superior egg shell weights and shell thickness when compared with limestone as a supplemental calcium source. Roland and Harms (1973) found that substitution of hen-sized or pullet-sized oyster shell or limestone in a 3.0% calcium laying diet improved egg shell quality during summer trials. Each of their trials lasted six weeks and utilized 30 birds per treatment. The hens were in their thirteenth month of production when the test began. The granulated form of the calcium source failed to have an effect on egg shell quality during the fall trials. Later, Roland *et al*. (1974) concluded that the larger particles of calcium carbonate had no influence on shell quality if the birds were receiving adequate calcium. This test was conducted for a six-week period during January and February with hens that were approximately 17 months of age and fed laying diets containing 2.75 or 4.75% calcium. In this study, large particle calcium carbonate was substituted for 2/3 of the finely ground limestone, with no significant affect on egg weight. The only statistically significant difference observed was in feed consumption of hens fed the 4.5% calcium diet without large calcium particles. Feed consumption was significantly less.

Charles et al. (1971) showed that oyster shell as a sole source of calcium in a 3.3% calcium laying diet improved egg shell breaking strength when compared to finely ground limestone, while a combination of both calcium sources produced slightly lower egg shell breaking strengths.

In an eight-week study, conducted during mid-summer and employing 30 hens per treatment, in approximately nine months production, Watkins et al. (1977) found that the particle size of the calcium source supplements did not significantly affect egg production, feed consumption, feed utilization or egg size. Egg shell strength was significantly improved by replacing 2/3 of the ground calcium with hen-sized calcium particles, regardless of the calcium level. This study agrees with the study of Miller and Sunde (1975) who found a definite trend of egg shells from coarse calcium sources to be more rigid than those from fine sources. In a 48-week study, using 30 young hens per treatment, Kuhl et al. (1977) reported that limestone particle size did not significantly influence egg production rate, feed efficiency, egg weight, or specific gravity when fed at three levels of calcium (2.5%, 3.0%, 3.5%). In a second experiment of 52 weeks duration, Kuhl et al. (1977) found that feed efficiency of hens fed only hen-sized oyster shell was significantly improved over those fed a mixture of pullet and hen-sized limestone or only pullet-sized oyster shell. Egg weights were significantly greater for hens receiving pullet-sized oyster shell. Egg shell breaking strength was significantly greater for hens fed a mixture of pullet and hen-sized limestone, when compared with pullet-sized limestone or hen-sized limestone.

Scott et al. (1971) attributed the improvement of egg shell strength, obtained from feeding hen-sized oyster shell, to the longer retention time of oyster shell in the gizzard, allowing the calcium to be "metered out" during the hen's period of fasting at night. Kuhl and Sullivan (1977) attempted to determine the solubility rates of two calcium sources. Twelve hours after force-feeding fasted hens either hen-sized oyster shell or hen-sized limestone, the hens were sacrificed and solubility rates calculated. Hen-sized oyster shell solubility rate was significantly greater than for hen-sized limestone (.33 g/hr vs. .288 g/hr), with the hen-sized limestone being retained in the gizzard for a longer period of time. In their in vitro study, there were no significant differences in the solubility rates between hen-sized oyster shell and hen-sized limestone. The in vitro solubility rate was slightly greater for pullet-sized than for hen-sized particles for both limestone and oyster shell.

Studies conducted on calcium sources for laying hens have produced a variety of results. Ground limestone and oyster shell have failed to show consistent significant differences in egg shell thickness, according to Arvat and Hinners (1973). Quisenberry et al. (1969) showed that the utilization of calcium from limestone was lower than that for oyster shell flour. In a study conducted by Muir *et al*. (1976), there were no significant differences for average egg weight or shell thickness among supplemental calcium treatments using limestone, Aragonite or oyster shell flour. The latter study agrees with the study conducted by Watkins *et al*. (1977) who employed limestone, oyster shell, or mined marine calcium sources.

This study was designed to investigate the effect of various particle sizes of different calcium sources on laying hen performance and egg shell quality.

EXPERIMENTAL PROCEDURE

Experiment 1

The purpose of this experiment was to determine the effects of three calcium sources with varying particle size on egg shell quality and laying hen performance. Previous studies have failed to show consistent significant differences in egg shell quality as related to calcium source. Commercially available Aragonite was tested against commonly fed supplemental calcium sources such as limestone and oyster shell in a pulverized and granular form.

In Experiment 1, 400 eighty-week old Colonial Mini hens were randomly assigned to four treatment groups, each containing four replications of twenty-five hens, housed two birds per cage (30 cm x 45 cm x 40 cm). Old hens were used because calcium source effects on egg shell characteristics should be detected earlier than in young hens. All hens were fed a practical 16% layer diet as shown in Table 1. Calcium sources, levels fed, and combinations used are shown in Table 2. A typical analysis for Aragonite is given in Table 3. Feed and water were supplied *ad libitum*.

Eggs were gathered daily and percent hen-day production and feed conversion were calculated at the end of each 28-day period for 12 weeks. During the last three days of each 28-day period, all eggs gathered were measured to establish the following parameters: 1) egg weight, 2) shell weight, 3) percent shell, 4) shell thickness, and 5) specific gravity.

TABLE 1. Composition of basal diet for experiment 1

Ingredients	%
Corn	64.95
Soybean meal (44%)	22.50
Alfalfa leaf meal (17%)	2.50
Calcium source*	7.50
Defluorinated phosphate (18% P, 32% Ca)	2.00
Vitamin premix**	.25
DL-methionine	.05
$MnSO_4$	.025
ZnO	.025
Salt	.20

*Table 2 indicates calcium sources for the dietary treatments.

**Vitamin premix supplies the following per kg of feed: 11,000 I.U. vitamin A; 3,300 I.C.U. vitamin D_3; 4.4 mg riboflavin; 11 mg Ca pantothenate; 13 mg vitamin B_{12}; 2.2 mg vitamin K (menadione sodium bisulfate); 5.5 I.U. d-alpha-tocopherol acetate; 27.5 mg niacin; 550 mg choline chloride.

TABLE 2. Dietary treatments for experiment 1

Treatments	Dietary calcium sources	Ca in diet
		%
1	Pulverized limestone	3.5
2	Aragonite*	3.5
3	Oyster shell flour	3.5
4	2/3 oyster shell flour + 1/3 oyster shell	3.5

*See Table 3 for a typical analysis of Aragonite.

TABLE 3. Typical analysis for Aragonite

Minerals	Content
Aluminum	138.0 ppm
Calcium	38-40%
Chlorine	.06%
Cobalt	3.00 ppm
Copper	10.00 ppm
Iron	56.00 ppm
Manganese	10.00 ppm
Magnesium	.17%
Potassium	.008%
Silica	.07%
Zinc	5.5 ppm

Analysis of variance was performed on egg weight, shell weight, percent shell, egg shell thickness, specific gravity, percent hen-day production, and feed conversion, as outlined by Steel and Torrie (1960). Treatment means were compared using Duncan's Multiple Range Test (1955).

Experiment 2

The purpose of the second experiment was to determine the effects of three calcium sources and combinations of sources on egg shell quality and laying hen performance, using birds of different ages and treatments from those in experiment 1.

In Experiment 2, 462 Babcock B-300V commercial egg-type laying hens were caged when 24 weeks of age. A total of seven treatments were utilized and replicated four times. Two replicates from each treatment were housed two birds per 30 cm x 45 cm x 40 cm cage and two replicates were housed as one bird per cage. All hens were fed a practical 19% layer diet shown in Table 4 with calcium sources, levels, and combinations as shown in Table 5. Feed and water were supplied ad libitum.

This study continued for fifteen 28-day periods. Eggs were collected daily and egg production computed on a hen-day basis. Feed was weighed back at the end of each 28-day period and feed efficiency determined. One day out of each week, all eggs laid by the birds were collected and subjected to the following measurements: 1) egg weight, 2) shell weight, 3) percent shell, 4) shell thickness, and 5) specific gravity.

TABLE 4. Experimental diets for experiment 2

Ingredients	Diets 1-6	Diet 7
	%	%
Corn	30.00	30.00
Milo	28.67	26.98
Soybean meal (44%)	30.00	30.33
Alfalfa leaf meal (17%)	1.50	1.50
Calcium source*	7.25	8.60
Defluorinated phosphate (18% P, 32% Ca)	2.00	2.00
Vitamin premix**	.25	.25
DL-methionine	.08	.09
$MnSO_4$	.025	.025
ZnO	.025	.025
Salt	.20	.20
% Protein	19.0	19.0
Kcal ME/kg	2647.7	2600.4
% Methionine	.373	.373
% Lysine	.9977	1.00
% Calcium	3.5	4.0
% Total phosphorus	.71	.709
mg Xanthophyll per kg	9.9	9.9

*Table 5 indicates calcium source for the dietary treatments.

**Vitamin premix supplies the following per kg of feed: 11,000 I.U. vitamin A; 3,300 I.C.U. vitamin D_3; 4.4 mg riboflavin; 11 mg Ca pantothenate; 13 mg vitamin B_{12}; 2.2 mg vitamin K (menadione sodium bisulfite); 5.5 I.U. d-alpha-tocopherol acetate; 27.5 mg niacin; 550 mg choline chloride.

Analysis of variance was performed on egg weight, shell weight, percent shell, egg shell thickness, specific gravity, percent hen-day production, and feed conversion in accordance with the procedures designated in Experiment 1.

TABLE 5. Experimental design for experiment 2

Groups*	Dietary calcium source	Ca in diet
		%
1	Pulverized limestone	3.5
2	Aragonite	3.5
3	Oyster shell flour	3.5
4	2/3 oyster shell flour + 1/3 hen-sized oyster shells**	3.5
5	2/3 Aragonite + 1/3 hen-sized oyster shells	3.5
6	2/3 pulverized limestone + 1/3 hen-sized oyster shells	3.5
7	Aragonite	4.0

*Groups 1-6 fed diets 1-6, respectively, Table 1, page 7.

**Hen-sized oyster shell was mixed in the diet.

RESULTS AND DISCUSSION

Experiment 1

In the 12-week study utilizing old laying hens, a general trend developed where the granular calcium sources produced better egg shell quality than the pulverized calcium sources (Table 6). There were no statistically significant differences in egg weight, shell weight, percent shell or specific gravity among calcium sources. The addition of 1/3 of the calcium source as hen-sized oyster shell consistently improved egg shell quality although not significantly in all cases, which is in agreement with Scott et al. (1971). Egg shell thickness was significantly greater (.382 vs .368 and .357 mm) in eggs from hens fed diets containing 2/3 oyster shell flour + 1/3 oyster shell than from the two diets containing pulverized calcium sources of oyster shell flour or pulverized limestone, respectively (Table 6). Aragonite also produced eggs with shells which were significantly thicker than those of pulverized limestone (.374 vs .357 mm) which is in disagreement with that of Muir et al. (1976) and Watkins et al. (1977). Oyster shell flour consistently produced better egg shell quality than that of limestone, but differences were not statistically significant. This agrees with the study conducted by Quisenberry et al. (1969) that the utilization of calcium from limestone was lower than that for oyster shell flour. Percent hen-day egg production and feed conversion were not significantly different among calcium sources fed (Table 7).

TABLE 6. Influence of calcium source on egg weight and egg shell quality for experiment 1

Treatments	Calcium sources	Calcium in diet (%)	Egg wt. (g)	Shell wt. (g)	Shell (%)	Thickness (mm)	Specific gravity
1	Pulverized limestone	3.5	64.33^{a*}	5.45^{a*}	8.42^{a*}	$.357^{c*}$	1.0717^{a*}
2	Aragonite	3.5	63.97^{a}	5.61^{a}	8.71^{a}	$.374^{ab}$	1.0733^{a}
3	Oyster shell flour	3.5	63.73^{a}	5.56^{a}	8.72^{a}	$.368^{bc}$	1.0724^{a}
4	Oyster shell flour 2/3 + oyster shell 1/3	3.5	63.87^{a}	5.71^{a}	8.84^{a}	$.382^{a}$	1.0734^{a}

*Means in columns with same letter are not significantly different ($P \leq .05$).

TABLE 7. Effect of three calcium sources on hen-day production and feed efficiency in old laying hens for experiment 1

Treatment	Calcium source	Hen-day production (%)	Feed conversion (kg feed/kg eggs)
1	Pulverized limestone	31.09[a*]	7.49[a*]
2	Aragonite	35.91[a]	6.65[a]
3	Oyster shell flour	37.56[a]	6.48[a]
4	Oyster shell flour 2/3 + oyster shell 1/3	31.66[a]	7.72[a]

*Values are not significantly different ($P \leq .05$).

Experiment 2

Neither calcium source nor level of calcium in the laying hen diet had a statistically significant effect on egg weight, percent hen-day egg production or feed conversion which is in agreement with the studies conducted by Watkins et al. (1977), Kuhl et al. (1977), and Miller and Sunde (1975) (Figure 4). Although there were no statistically significant differences in feed conversion in this study, the hens fed diets containing one-third of the calcium source supplied by the addition of hen-sized oyster shells consumed more feed/kg of eggs (2.4135 vs 2.3867 kg) than hens fed diets whose calcium was supplied as strictly pulverized calcium carbonate at the level of 3.5% calcium in the diet (Table 8). The hens fed the diet whose calcium was supplied by 2/3 aragonite + 1/3 oyster shells consistently had the best egg shell quality and pulverized limestone consistently had the poorest egg shell quality at the level of 3.5% calcium in the diet as determined by shell weight, percent shell, egg shell thickness and specific gravity. The substitution of one-third of the calcium in the 3.5% calcium diet as hen-sized oyster shell consistently produced eggs with better egg shell quality (groups 4, 5, 6) than eggs from diets of strictly pulverized calcium sources (groups 1, 2, 3) as seen in Figures 1-3. There were no significant differences in egg weight (58.86 g vs. 58.80 g) between levels of calcium in the diets of 3.5% and 4.0% calcium, respectively.

TABLE 8. The effects of calcium sources on hen-day production and feed efficiency for experiment 2

Treatment	Calcium source	Hen-day production (%)	Feed conversion (kg feed/kg eggs)	Feed consumption (g/hen/day)	Calcium consumed (g/hen/day)
1	Pulverized limestone	76.66	2.44	111.51	3.90
2	Aragonite	79.62	2.35	113.06	3.95
3	Oyster shell flour	77.13	2.37	110.22	3.86
4	2/3 oyster shell flour + 1/3 oyster shells	76.74	2.53	115.54	4.04
5	2/3 aragonite + 1/3 oyster shells	76.40	2.53	114.94	4.02
6	2/3 pulverized limestone + 1/3 oyster shells	77.15	2.48	112.76	3.95
7	Aragonite	78.24	2.33	107.62	4.31

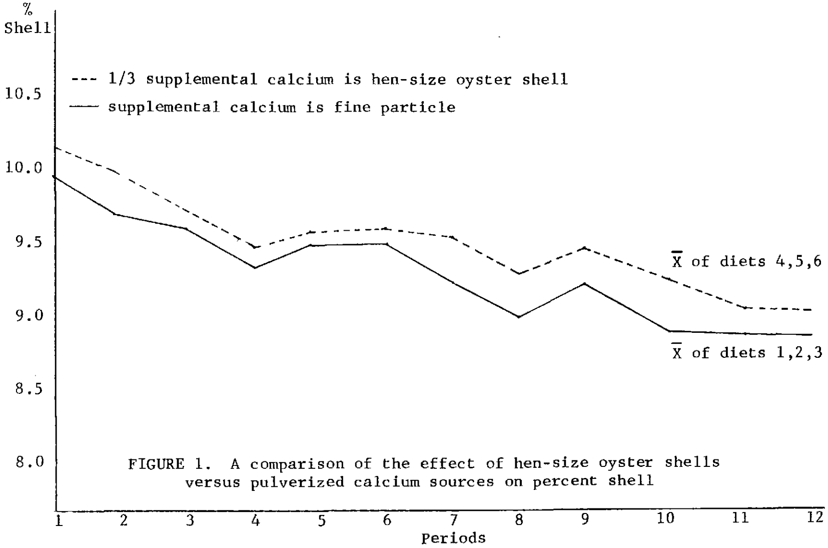

FIGURE 1. A comparison of the effect of hen-size oyster shells versus pulverized calcium sources on percent shell

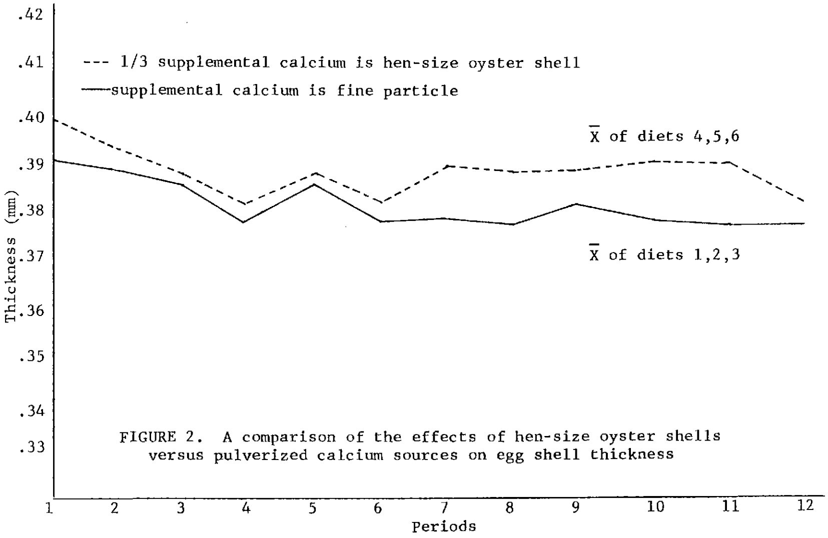

FIGURE 2. A comparison of the effects of hen-size oyster shells versus pulverized calcium sources on egg shell thickness

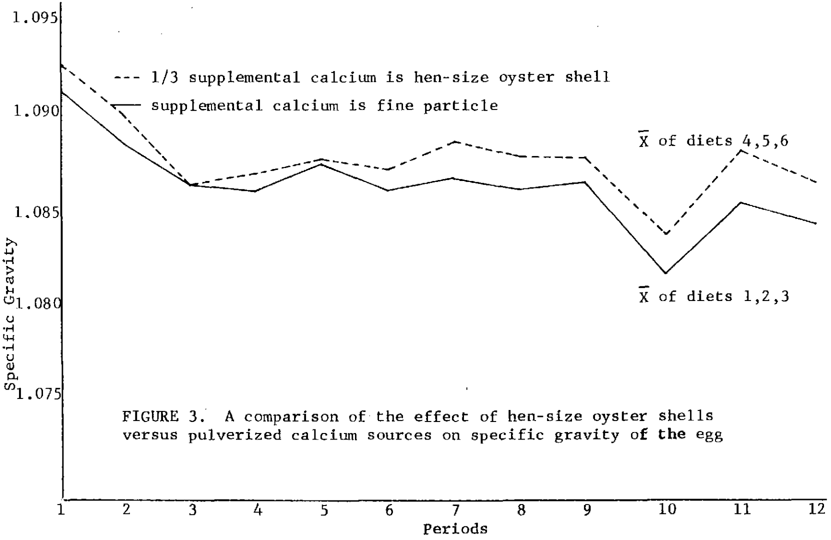

FIGURE 3. A comparison of the effect of hen-size oyster shells versus pulverized calcium sources on specific gravity of the egg

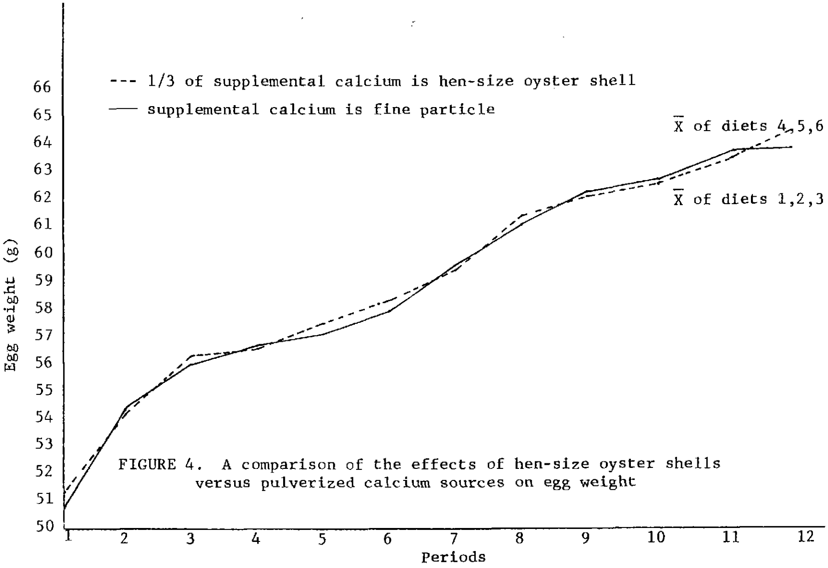

FIGURE 4. A comparison of the effects of hen-size oyster shells versus pulverized calcium sources on egg weight

Egg shell weight was significantly increased due to the substitution of one-third of the pulverized calcium source with hen-sized oyster shell in the laying diets containing 3.5% calcium (5.583 vs. 5.426 g). The heaviest egg shells were produced from the diet consisting of 2/3 aragonite + 1/3 oyster shells. This treatment group had significantly heavier shells (5.63 vs. 5.52, 5.50, 5.44, 5.42, 5.42 g) than the treatments receiving 2/3 pulverized limestone + 1/3 oyster shell (3.5% calcium), aragonite at the 4.0% calcium level, oyster shell flour (3.5% calcium), aragonite (3.5% calcium) and pulverized limestone (3.5 % calcium), respectively. The diet containing 2/3 oyster shell flour + 1/3 oyster shell also produced eggs with significantly heavier shells (5.60 vs. 5.50, 5.44, 5.42, 5.42 g) than shells from aragonite (4.0% calcium), oyster shell flour (3.5% calcium), aragonite (3.5% calcium) and limestone (3.5% calcium), respectively (Table 9). There were no statistically significant differences in shell weight among pulverized calcium sources regardless of the level of calcium in the diet (Table 9).

Percent shell was also improved by the addition of hen-sized oyster shell to the layer ration. Diets containing 3.5% calcium with a calcium source of 2/3 aragonite + 1/3 oyster shell or 2/3 oyster shell flour + 1/3 oyster shell (groups 5 and 4) significantly improved percent shell (9.52 and 9.50% vs. 9.30, 9.20, 9.20%) over the diets of groups 3, 2, and 1, containing calcium sources of oyster shell flour, aragonite and pulverized limestone at the level of 3.5% calcium, respectively (Table 9). Eggs from the diets containing 2/3 pulverized

TABLE 9. Egg weight and shell quality as affected by calcium source and levels for experiment 2

Treatments	Calcium sources	Calcium in diet (%)	Egg wt. (g)	Shell wt. (g)	Shell (%)	Thickness (mm)	Specific gravity
1	Pulverized limestone	3.5	59.02[a*]	5.42[c*]	9.20[c*]	.376[d*]	1.0858[d*]
2	Aragonite	3.5	58.49[a]	5.42[c]	9.29[bc]	.379[cd]	1.0864[cd]
3	Oyster shell flour	3.5	58.66[a]	5.44[c]	9.30[bc]	.381[c]	1.0867[bcd]
4	2/3 oyster shell flour + 1/3 oyster shells	3.5	59.12[a]	5.60[ab]	9.50[a]	.388[ab]	1.0876[ab]
5	2/3 aragonite + 1/3 oyster shells	3.5	59.13[a]	5.63[a]	9.52[a]	.389[a]	1.0881[a]
6	2/3 pulverized limestone + 1/3 oyster shells	3.5	58.74[a]	5.52[bc]	9.41[ab]	.384[bc]	1.0872[abc]
7	Aragonite	4.0	58.80[a]	5.50[c]	9.37[abc]	.383[bc]	1.0873[abc]

*Means in columns with the same letters are not significantly different ($P \leq .05$).

limestone + 1/3 oyster shell also produced a significantly (9.41 vs 9.20%) greater percent shell than eggs from hens fed pulverized limestone at the level of 3.5% calcium in the diet. Aragonite at the level of 4.0% calcium in the diet improved percent shell (9.37 vs. 9.30, 9.29, 9.20%) although not significantly when compared to oyster shell flour, aragonite or pulverized limestone at the level of 3.5% calcium in the diet. There were no statistically significant differences in percent shell between pulverized calcium sources at the level of 3.5% calcium in the laying diet, but oyster shell flour and aragonite did produce eggs with a higher percent shell (9.30 and 9.29 vs. 9.20%) than that of pulverized limestone.

The diets which contained the calcium source as 2/3 aragonite + 1/3 oyster shell or 2/3 oyster shell flour + 1/3 oyster shell produced eggs with significantly thicker egg shells (.389 and .388 vs. .381, .379, .376 mm) than when the calcium sources were oyster shell flour, aragonite or limestone. Also, the substitution of 1/3 of the pulverized limestone for hen-sized oyster shell in a 3.5% calcium laying diet significantly improved egg shell thickness (.384 vs. .376 mm). Significantly thicker egg shells were produced in eggs from diets which contained calcium sources of aragonite (4.0% calcium) and oyster shell flour (3.5% calcium) than that of pulverized limestone (.383 and .381 vs. .376 mm), respectively. These results are similar to those reported by Quisenberry and Walker (1970) who found that feeding oyster shell to laying hens produced superior egg shell weights and thickness when compared to limestone. Aragonite when fed at a level of 4.0% calcium in a laying hen diet as compared to aragonite of 3.5% calcium in the diet improved egg shell thickness (.383 vs. .379 mm) although not significantly (Table 9, page 24).

There were no significant differences in specific gravity among calcium sources in which 1/3 of the calcium was supplied as hen-sized oyster shell. Eggs with the highest specific gravity were produced from diets containing 2/3 aragonite + 1/3 oyster shell followed by those from diets containing 2/3 oyster shell flour + 1/3 oyster shell (1.0881 and 1.0867). Specific gravity from eggs from hens fed diets containing 2/3 aragonite + 1/3 oyster shell were significantly greater (1.0881 vs. 1.0867, 1.0864, 1.0858) than eggs produced from diets containing a calcium source of oyster shell flour, aragonite, or limestone, respectively, when fed at a 3.5% dietary level of calcium. Also, eggs from hens fed diets containing 2/3 oyster shell flour + 1/3 oyster shell as a calcium source had significantly higher specific gravity (1.0876 vs. 1.0864, 1.0858) than eggs from diets containing calcium sources of aragonite and pulverized limestone, respectively. Eggs from hens fed diets containing aragonite supplying a level of 4.0% calcium in the diet or 2/3 limestone + 1/3 oyster shell also produced eggs with significantly higher specific gravity (1.0873 and 1.0872 vs. 1.0848) than that of pulverized limestone, respectively. There were no statistically significant differences in specific gravity of eggs from among pulverized calcium sources at the level of 3.5% dietary calcium. However, the eggs from hens fed diets containing oyster shell flour and aragonite had higher specific gravities (1.0867 and 1.0864 vs. 1.0858) than those from hens receiving pulverized limestone, respectively, although not significantly so (Table 9, page 24).

There were no significant differences in feed conversion (2.37 vs. 2.44 kg feed/kg eggs) or calcium intake (3.86 vs. 3.90 kg feed/kg eggs) between the calcium sources of oyster shell flour and pulverized limestone, respectively. The data indicate that the utilization of calcium from oyster shell was greater than that of limestone which is in agreement with the studies conducted by Charles et al. (1971), Quisenberry et al. (1969) and Quisenberry and Walker (1970).

With the large amounts of weekly data collected it was possible to run correlations between egg weight, egg shell weight, percent shell, egg shell thickness and specific gravity for each individual calcium feeding program. Although not valid in determining the best calcium feeding program, it establishes a good basis for determining indicators of egg shell quality (Tables 10-16).

The correlations between egg weight, egg shell weight, percent shell, egg shell thickness and specific gravity were consistent in direction from one calcium feeding program to the other, except in the case of the correlation between egg shell weight and egg shell thickness. This correlation was not statistically significant for any of the calcium feeding programs utilized and ranged from +.11 to -.19.

In all calcium feeding programs, the correlation between egg weight and shell weight was strongly positive, ranging from +.66 to +.87 and highly significant statistically. This indicates that as egg weight goes up, the

TABLE 10. The correlation between egg shell quality parameters where pulverized limestone has been fed

	Egg weight (g)	Shell weight (g)	% shell	Thickness (mm)	Specific gravity
Egg weight (g)	1.00	.86*	-.87*	-.49*	-.65*
Shell weight (g)		1.00	-.51*	-.18	-.42*
% shell			1.00	.67*	.71*
Thickness (mm)				1.00	.62*
Specific gravity					1.00

*P $\leq$ .01

TABLE 11. The correlation between egg shell quality parameters where Aragonite (3.5% Ca) has been fed

	Egg weight (g)	Shell weight (g)	% shell	Thickness (mm)	Specific gravity
Egg weight(g)	1.00	.67**	-.92**	-.73**	-.83**
Shell weight (g)		1.00	-.32*	-.14	-.41**
% shell			1.00	.86**	.85**
Thickness (mm)				1.00	.78**
Specific gravity					1.00

*P $\leq$ .05
**P $\leq$ .01

TABLE 12. The correlation between egg shell quality parameters where 2/3 aragonite + 1/3 oyster shells has been fed

	Egg weight (g)	Shell weight (g)	% shell	Thickness (mm)	Specific gravity
Egg weight (g)	1.00	.87**	-.83**	-.37**	-.61**
Shell weight (g)		1.00	-.46**	.004	-.35*
% shell			1.00	.62**	.71**
Thickness (mm)				1.00	.62**
Specific gravity					1.00

*P $\leq$ .05
**P $\leq$ .01

TABLE 13. The correlation between egg shell quality parameters where 2/3 limestone + 1/3 oyster shells has been fed

	Egg weight (g)	Shell weight (g)	% shell	Thickness (mm)	Specific gravity
Egg weight (g)	1.00	.82**	-.83**	-.36**	-.58**
Shell weight (g)		1.00	-.36*	.12	-.24
% shell			1.00	.71**	.72**
Thickness (mm)				1.00	.66**
Specific gravity					1.00

*P $\leq$ .05
**P $\leq$ .01

TABLE 14. The correlation between egg shell quality parameters where oyster shell flour has been fed

	Egg weight (g)	Shell weight (g)	% shell	Thickness (mm)	Specific gravity
Egg weight (g)	1.00	.79*	-.87*	-.46*	-.71*
Shell weight (g)		1.00	-.39*	.0142	-.39*
% shell			1.00	.72*	.76*
Thickness (mm)				1.00	.68*
Specific gravity					1.00

*P $\leq$ .01

TABLE 15. The correlation between egg shell quality parameters where 2/3 oyster shell flour + 1/3 oyster shells has been fed

	Egg weight (g)	Shell weight (g)	% shell	Thickness (mm)	Specific gravity
Egg weight(g)	1.00	.87*	-.89*	-.50*	-.67*
Shell weight (g)		1.00	-.57*	-.20	-.49*
% shell			1.00	.66*	.70*
Thickness (mm)				1.00	.60*
Specific gravity					1.00

*P $\leq$ .01

TABLE 16. The correlation between egg shell quality parameters where Aragonite (4% Ca) has been fed

	Egg weight (g)	Shell weight (g)	% shell	Thickness (mm)	Specific gravity
Egg weight (g)	1.00	.86**	-.90**	-.55**	-.70**
Shell weight (g)		1.00	-.56**	-.29*	-.49**
% shell			1.00	.67**	.74**
Thickness (mm)				1.00	.53**
Specific gravity					1.00

*P $\leq$ .05
**P $\leq$ .01

shell weight also goes up, but not at the same rate.

The correlations between egg weight and percent shell, shell thickness and specific gravity were all strongly negative and highly significant, regardless of the calcium feeding program. The weakest correlation between egg weight and these three measurements was observed between egg weight and shell thickness, where the correlation ranged from -.36 to -.73. The strongest and most consistent correlation was obtained between egg weight and percent shell. These correlations were found to range from -.82 to -.92 when compared across calcium feeding programs. The correlation between egg weight and specific gravity was somewhat variable, ranging from -.58 to -.83. It cannot be determined from these data if the calcium feeding program produced this variation in magnitude of the correlation. The above correlations all suggest that as the hens get older, egg weight increases while percent shell, shell thickness and specific gravity all tend to decrease. The decreased ability of the hen to utilize the calcium available to her as she ages is indicated by these correlations.

The correlation between shell weight and percent shell, shell thickness and specific gravity are not as large as the correlation between egg weight, egg shell weight, percent shell, egg shell thickness and specific gravity. The correlations between egg weight and percent shell and specific gravity were also found to be negative and highly significant, and of the order of - 40 $\pm$ .15. Shell weight was not significantly correlated with shell thickness.

All the correlations among percent shell, shell thickness and specific gravity are strongly positive and highly significant and of the order of +.70.

It would appear, because of the size of the correlations, that percent shell should be a consistent indicator of egg shell quality, followed closely by specific gravity. Shell thickness appeared to be the poorest indicator of egg shell quality. Shell thickness also showed the poorest relationship to egg shell weight.

SUMMARY

Two experiments were conducted with two different ages of commercial egg-type laying hens fed diets in which the calcium source, calcium level and combination of calcium sources varied in order to determine which source and combination produced the best egg shell quality.

In Experiment 1, where twenty-month old commercial laying hens were utilized, the substitution of hen-sized oyster shell for part of the pulverized calcium source improved egg shell quality, although not statistically significant in all cases, in a 12-week study. It was determined that Aragonite could be used as an acceptable calcium source for laying hens. Hens fed Aragonite produced eggs with superior egg shells, when compared to the eggs from hens fed pulverized limestone. There were no significant differences in percent egg production or feed conversion which could be associated with the source of calcium.

In Experiment 2, it was found that the substitution of one-third of the supplemental calcium as large particle calcium carbonate in a laying hen diet improved egg shell quality. As in Experiment 1, percent egg production, feed conversion and egg weights were not significantly affected by the source or particle size of the supplemental calcium. Utilization of calcium from oyster shell was consistently greater than that of limestone.

It was concluded that the addition of large particle oyster shells do improve egg shell quality when substituted as part of the pulverized calcium source. Aragonite also proved to be a potential calcium source for commercial laying hens. The data indicated that the calcium from oyster shell is more available than that from limestone.

It was found that percent shell and specific gravity are consistent indicators of egg shell quality. It was also determined that shell thickness is the poorest indicator of egg shell quality and had the poorest relationship to egg shell weight.

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