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EFFECT OF DIETARY CALCIUM LEVEL ON EGG PRODUCTION AND EGG SHELL QUALITY IN BROILER BREEDER HENS FROM 36 TO 60 WEEKS OF AGE

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ABSTRACT: *This study was conducted to evaluate the effects of different calcium (Ca) levels in diet on shell quality and egg production of Ross broiler breeder hens from 36 to 60 weeks of age. A total of 198 pullets were reared on restricted diets with 1.0, 1.5 and 2.0% Ca, up to 22 weeks. The pullets in each experimental diet were further randomly divided into three treatments with 1.5, 2.5 and 3.5% dietary Ca (66 birds per treatment) and fed from 23 to 60 weeks. The hens were caged individually. The cages were fitted with feed troughs and water nipples. Birds were fed breeder diet (23 to 34 weeks), breeder diet phase 2 (35 to 46 weeks) and breeder diet phase 3 (47 to 60 weeks) feed intake was administered according to Ross Breeders recommendations. The rations were isocaloric and isonitrogenous with different levels of Ca and P and were administered according to Ross Breeders Recommendations. Dietary treatment significantly (P<0.0001) affected Ca intake of broiler breeder hens. An average Ca intake (g/hen/day) of 2.14, 3.76 and 5.39 for the 1.5, 2.5 and 3.5% Ca levels, respectively occurred during the experimental period. Egg production, egg weight, egg mass, egg contents and shell weight/unit surface area (SWUSA), shell weight, shell percentage and shell thickness increased (P<0.0001) when dietary Ca was raised from 1.5% to 2.5%. However, no significant (P>0.05) differences were found in these variables between 2.5 and 3.5% Ca levels. All the eggshell quality variables increased over time while egg mass and egg production declined. From the results of the present study, it is concluded that increasing Ca level from 1.5 to 2.5% could improve eggshell quality. Present results suggest that the 2.5% Ca (3.8 g Ca/hen/day) seems to be adequate to support egg production and improving eggshell quality of broiler breeders.*

ORIGINAL ARTICLE

Keywords: Calcium, egg production, eggshell quality, egg weight, phosphorus,

INTRODUCTION

The ability of hens to produce quality shells depends largely on the availability of calcium (Ca) from ingested food and skeleton (Farmer et al., 1983). It is claimed (Klasing, 1998) that the amount of dietary Ca required for maximising bone or eggshell mineralisation and strength is greater than that needed for other functions. Therefore, proper build-up of Ca stores is essential for the maintenance of bone integrity and acceptable shell quality (Robinson, 1999).

The term "shell quality" is frequently used as a synonym for "shell strength", and denotes the ability of eggshells to withstand externally applied forces without cracking or breaking (Hamilton, 1982). Eggshell quality can be defined by variables such as egg specific gravity (ESG) through its relationship to shell porosity as shown by positive correlation with pore concentration (Peebles and Brake, 1987). Factors that affect the strength of eggshells are heredity, clutch position, rate of production (Hammerle, 1969) age, health status (disease), season, temperature, nutrition (Hammerle, 1969; Wolford and Tanaka, 1970), strain of hen, time of the day eggs are laid, eggshell ultrastructure (Hamilton et al., 1979a,b), housing system, length of lay and neuro-humoral reproductive control mechanisms (Wolford and Tanaka, 1970). The most common physical properties associated with eggshell strength

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are shell thickness and shell egg specific gravities. Richards and Staley (1967) suggested that shell thickness, shell weight, shell percentage and shell weight per unit surface area (SWUSA), may be classified as shell quality measurements, as these variables are significantly ($P<0.01$) correlated with each other.

As the hen gets older, minimisation of handling loss by maintenance of eggshell quality becomes more important than egg weight. Shell quality is governed by the quantity of the SWUSA of the egg. Shell deposition increases for several months and then plateaus, as the hen gets older. Since egg weight increases throughout the laying period, once shell deposition plateaus, shell quality declines. In this regard, dietary Ca content is important as shell deposition and quality are directly related to the level of Ca in the diet (Ousterhout, 1980).

Because feed intake is restricted in broiler breeder hens, with most feed being consumed during the early morning hours, these and especially older breeder hens may be more susceptible to periods of Ca deficiency during shell formation than hens that are fed *ad libitum* (Farmer et al., 1983). The present study was undertaken to gain additional information on the effects of three dietary Ca levels on shell quality and egg production of broiler breeder hens from 36 to 60 weeks of age.

MATERIALS AND METHODS

Birds and husbandry

A total of 198 Ross broiler breeder pullets were reared on restricted diets with 1.0, 1.5 and 2.0% Ca treatment up to 22 weeks of age. The pullets in each experimental diet were further randomly divided into three treatments with 1.5, 2.5 and 3.5% dietary Ca (66 birds per treatment) and fed from 23 to 60 weeks. The hens were placed in individual cages within a common room. The cages were fitted with feed troughs, water nipples and perches. The hens were photostimulated at 22 weeks of age and received 16 hours of light starting from week 26 of age. This photo schedule was continued to 60 weeks of age.

Birds were fed pre-breeder diet from 19 to 22 weeks of age, breeder diet phase 1 (23 to 34 weeks), breeder diet phase 2 (35 to 46 weeks) and breeder diet phase 3 (47 to 60 weeks). The feed intake was administered in accordance with Ross Breeders recommendations. Individual body weight measurements were taken on three weekly intervals for the duration of the experiment.

Experimental parameters measured

Egg parameters: Egg numbers were recorded daily and summarised on a weekly basis throughout the experimental period. Abnormal eggs having multiple yolks, shell-less and those with defective shells were recorded. Shell-less eggs were, however, not included in the weight data. Cumulative egg production was calculated on a per bird basis throughout the experimental period. Percent lay on daily basis was calculated using a formula given by North and Bell (1990).

Individual egg weights were recorded for all the eggs produced by each hen on daily basis throughout the test period. After the mean egg weight had been determined in grams each, daily egg mass was computed by multiplying percent hen day production by mean egg weight (North and Bell, 1990).

Eggshell quality: Eggshell thickness was determined according to the procedures of Ehtesham and Chowdhury (2002) and Kul and Seker (2004). The eggshells from individual eggs were then placed in crucibles and dried overnight in the oven at 60 ° C and cooled in the desiccators for approximately 30 minutes, and weight was recorded. The weight of egg contents was calculated by subtracting shell weight from egg weight. Shell percentage was calculated by dividing dry shell weight by egg weight and multiplying by 100 (Chowdhury and Smith, 2001). The surface area (cm^2) of each egg was calculated using the formula of Carter (1975), $3.9782W^{.7056}$, where W is the egg weight in grams. Shell weight was divided by egg surface area to give the SWUSA expressed as mg/cm^2 (Wells, 1967).

Statistical analyses

Calcium level during the rearing period (one day old to 18 weeks) had no significant effect on bone measurements. Therefore, the effects of dietary Ca level and age on the egg characteristics data during laying period (36 to 60 weeks) were analysed as a 3 × 9 factorial block design in which data from individual birds (22 birds per treatment) served as replicates. Data were subjected to ANOVA using the General Linear Models procedure (SAS Institute, 1996) to assess the effect of dietary Ca level and age on response variables relating to egg production, egg mass, egg weight, shell thickness, shell weight and shell percentage. The differences between treatment means were separated using Tukey's studentised range (Honestly Significant Difference, HSD) test.

RESULTS AND DISCUSSION

Calcium intake

As illustrated in Table 1, dietary Ca levels had a significant ($P<0.0001$) effect on Ca intake of the hens throughout the laying period. An average Ca intake (g/hen/day) of 2.14, 3.76 and 5.39 for the 1.5, 2.5 and 3.5% Ca levels, respectively occurred during the experimental period (36 to 60 weeks). Ca intake in the hens increased ($P<0.05$) as dietary Ca was concentration raised from 1.5 to 3.5%. These results are consistent with those of Clunies

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(1992a) and Keshavarz and Nakajima (1993) who fed laying hens Ca levels ranging from 2.5 to 5.5% and found that Ca intake increased with increasing dietary level of Ca. A significant (P<0.0001) Ca level × age interaction occurred.

Low Ca intake values of hens were noted at 39 weeks compared to other age periods (Table 1). High ambient temperature above the comfort zone could be a contributory factor to the lower Ca intake values during this period. The average maximum temperatures at 36, 39 and 42 weeks were 32.6, 35.6 and 30.9 ° C, respectively. The Ca intake of hens did not appear to decline with age until 54 weeks where after Ca intake started to decline.

Table 1 - Effect of dietary calcium levels and age on calcium intake of broiler breeder hens

Age (weeks)	Dietary level of calcium		
	1.5%	2.5%	3.5%
36	2.27±0.06[a]	3.90±0.06[b]	5.50±0.06[c]
39	1.91±0.06[a]	3.42±0.06[b]	4.77±0.06[c]
42	2.18±0.06[a]	3.81±0.06[b]	5.82±0.06[c]
45	2.28±0.06[a]	3.99±0.06[b]	5.78±0.06[c]
48	2.12±0.06[a]	3.59±0.06[b]	5.21±0.06[c]
51	2.19±0.06[a]	3.92±0.06[b]	5.62±0.06[c]
54	2.18±0.06[a]	4.02±0.06[b]	5.88±0.06[c]
57	2.09±0.06[a]	3.65±0.06[b]	5.18±0.06[c]
60	2.03±0.06[a]	3.51±0.06[b]	5.18±0.06[c]
CV%	10.9		
Significance level (P)			
Treatment	0.0001		
Age	0.0001		
Interaction	0.0001		

[a,b,c]Means within a rows with no common superscripts differ significantly (P<.05).

Egg production

Dietary Ca level had a significant (P<0.001) effect on egg production. From the results of current study, it is evident that hen day egg production from week 36 for birds fed 1.5% Ca diets was in general significantly (P<0.05) lower than those fed the 2.5 and 3.5% Ca diets. These results are consistent with reports of Ahmad et al. (2003) and Clunies et al. (1992b) in commercial laying hens. Accordingly, Atteh and Leeson (1983) and Manley et al. (1980) reported no effect of feeding Ca levels ranging from 2.5 to 4.2% on egg production in commercial laying hens and turkey breeder hens. The mean hen day percent production values during the entire laying period for the 1.5, 2.5 and 3.5% dietary Ca levels were 62.84 ± 0.49, 66 ± 0.47 and 67.46 ± 0.46, respectively. The hens received 3.5% dietary Ca laid at a rate 1.7% higher than those that received 2.5% Ca diets. The average number of eggs produced by each hen from 25 to 60 weeks of age (245 days) for the 1.5, 2.5 and 3.5 Ca levels was 150.21 ± 3.24, 161 ± 3.14 and 165 ± 3.11, respectively. The yearly egg production from birds fed 2.5 and 3.5% Ca diets was in agreement with Ciacciariello and Gous (2002) who reported that a broiler breeder hen produces about 165 eggs in the 60 weeks of production life.

Rose (1997) reported the decline in egg production immediately after peak production to lengthening of egg formation time. A slow and continuous reduction in the rate of egg yolk deposition as the bird age also contributes to a decline in egg production.

The effect of Ca level and age on egg mass is shown in Figure 1. In accordance with egg production egg mass was significantly (P<0.05) lower for birds fed 1.5% Ca diets compared to 2.5 and 3.5% Ca diets (Figure 1). No statistical (P>0.05) differences were observed between the 2.5 and 3.5% dietary Ca levels. As shown in Figure 1, egg mass in accordance with egg production significantly (P<0.0001) declined with age. This is in agreement with Rose (1997) who stated that egg mass output rises to a peak shortly after a flock has reached peak egg production and thereafter decline steadily until egg production ceases.

Mortality

Ali et al. (2003) reported that mortality plays a major role in determining performance of the broiler breeder enterprise, as it is a function of the dead and culled birds over the growth and production period. Higher mortality has been associated to adversely affect laying performance of broiler breeders. In the present study, mortality included birds that died or culled from a flock during the second laying cycle (i.e., 36 to 60 weeks). Nine hens (3 from each treatment) died during this phase, indicating that Ca level had no effect on mortality. Atkinson (1967), Pepper et al. (1968) and Scott et al. (1999, 2000) observed similar results when they fed turkey hens and Shaver Starcross hens diets supplemented with different levels of Ca (arranged from 1.24 to 6.0%).

Eggshell quality

The mean values for egg weight (g), shell weight (g), egg contents (g), egg surface area (cm^2), shell percentage shell, SWUSA (mg/cm^2) and eggshell thickness (sharp end, equator and broad end) (mm) are presented in Table 2. As illustrated in Table 2, the feeding of 2.5 and 3.5% Ca diet resulted in greater egg weight, shell weight, egg contents, egg surface area, shell percentage and shell thickness than the lower level (1.5% Ca). No significant (P>0.05) differences in these variables were found between the 2.5 and 3.5% Ca diet levels.

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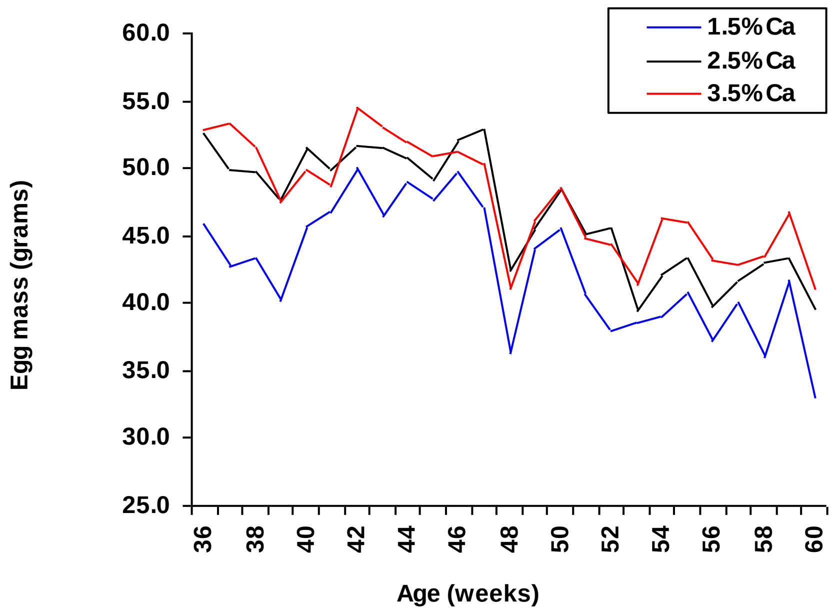

Fig. 1- Effect of dietary Ca levels and age on egg mass

Egg weight tended to increase by about 1.0% as Ca level increased from the 2.5 to 3.5%. The results of the present study agree with the findings of Summers et al. (1976) who reported linear increase in egg weight with higher level of Ca (2.96 *vs.* 1.50%). These results are also in accordance with Ahmad *et al.* (2003), Atteh and Leeson (1983), and Zapata and Gernat (1995) who reported that increasing dietary Ca level from 2.5 to 5.0, 3.0 to 4.2 and 3.0 to 3.5%, respectively had no effect on egg weight. These results are, however, in partial agreement with previous reports of Reddy et al. (1968), Roland et al. (1996) and Scott et al. (2000) who reported either non-significant differences in egg weight or significant (P>0.05) decreases in egg weight due to feeding increased levels of Ca. These results are, however, in contrast with the results of the first phase of the laying cycle (25 to 35 weeks), where no significant (P<0.05) differences in egg weight was observed due to increases in dietary Ca level. According to these results, the effect of different dietary Ca levels on egg weight appears during the later stages of the laying period.

As already mentioned, egg contents significantly (P<0.0001) increased as dietary Ca concentration increased from 1.5 to 2.5%. Thereafter, further increases resulted in non-significant (P>0.05) increase in egg contents (Table 2). An increase in egg contents could be attributable to increases in egg and shell weights since egg contents are a function of these two parameters.

As already mentioned, egg contents significantly (P<0.0001) increased as dietary Ca concentration increased from 1.5 to 2.5%. Thereafter, further increases resulted in non-significant (P>0.05) increase in egg contents (Table 2). An increase in egg contents could be attributable to increases in egg and shell weights since egg contents are a function of these two parameters.

As indicated in Table 2 egg surface area was significantly (P<0.05) influenced by dietary Ca level up to 2.5%. Thereafter, there were no further statistically significant (P>0.05) increases in egg surface area. Egg surface area significantly (P<0.0001) increased over time (Table 2). The increase in egg surface area could be attributable to increases in egg weight due to age. These two variables are highly positively correlated (r = 1.00).

It was observed that shell percentage tended (P>0.05) to plateau as dietary Ca level increased from 2.5 to 3.5% and this occurred between 36 and 39 weeks of age. Thereafter, shell percentage was not significantly (P>0.05) different among Ca levels (Table 2). These results are in disagreement with those of Reddy et al. (1968) who reported that feeding commercial layers diets containing 3.85 and 3.05% Ca resulted in significantly (P<0.05) greater shell percentage than lower levels (i.e., 2.25% and 2.65% Ca). From 25 to 35 weeks, shell percentage increased significantly (P<0.05) with increased Ca level. The study of Kul and Seker (2004) in quails demonstrated that shell percentage decreased with increased egg weight. Similar observations were made in the current study.

From Table 2 it is evident that the SWUSA was significantly (P>0.05) lower for 1.5% Ca diets compared to 2.5 and 3.5% Ca diets. The SWUSA was not significantly (P>0.05) different among dietary Ca levels at 42, 45, 48, 51, 54 and 60 weeks of age. These results are consistent with those of Ousterhout (1980) who reported that SWUSA increased by 1.25 mg when dietary Ca was increased by 1.0% (*i.e.*, from 3.75 to 4.75%). In the present study, SWUSA increased by 1.62 mg/cm^2 as Ca level increased from 1.5 to 2.5%. Table 2, illustrated that dietary Ca level had a significant (P<.05) effect on SWUSA only at 36 and 39 weeks of age. These results agree with findings of Nordstrom and Ousterhout (1982) who reported that SWUSA decreased significantly (P<.05) with increasing egg weight.

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Table 2 - The effect of dietary calcium level and age on egg weight and eggshell parameters

		Age in weeks										Significance of effect (P)			
Variable	Treatment	36	39	42	45	48	51	54	57	60	Means	Treatment	Age	Interaction	CV
Egg weight (g)	1.5% Ca	62.75±0.66	62.86±0.77	66.95±0.65	69.72±0.69	71.09±0.79	71.59±0.82	72.25±0.87	72.62±0.87	73.41±1.16	69.25±0.27[a]	0.0001	0.0001	0.9830	6.2
	2.5% Ca	64.15±0.61	65.21±0.65	68.12±0.63	70.86±0.69	71.74±0.69	72.70±0.75	74.55±0.78	74.09±0.87	73.73±0.95	70.57±0.25[b]				
	3.5% Ca	64.99±0.62	65.70±0.69	68.89±0.65	71.14±0.68	72.24±0.66	73.85±0.72	73.76±0.73	73.74±0.79	75.96±0.92	71.14±0.24[b]				
	Means	63.96±0.36[a]	64.59±0.41[a]	68.00±0.37[b]	70.57±0.40[c]	71.69±0.41[c]	72.71±0.44[cd]	73.52±0.46[cd]	73.48±0.49[cd]	74.36±0.59[d]					
Shell weight (g)	1.5% Ca	5.12±0.07[a]	5.00±0.09[a]	6.02±0.07[a]	6.14±0.08[a]	6.11±0.09[a]	6.29±0.09[a]	6.41±0.10[a]	6.16±0.10[a]	6.31±0.13[a]		0.0001	0.0001	0.0001	8.0
	2.5% Ca	5.70±0.07[b]	5.71±0.07[b]	6.02±0.07[a]	6.30±0.08[a]	6.32±0.08[ab]	6.49±0.09[a]	6.63±0.09[a]	6.54±0.10[b]	6.46±0.11[a]					
	3.5% Ca	5.81±0.07[b]	5.79±0.08[b]	6.07±0.07[a]	6.26±0.07[a]	6.40±0.07[b]	6.43±0.08[a]	6.56±0.08[a]	6.54±0.09[b]	6.69±0.10[a]					
Egg contents (g)	1.5% Ca	57.63±0.62	57.87±0.72	60.93±0.61	63.58±0.65	64.98±0.75	65.30±0.77	65.84±0.82	66.45±0.82	67.10±1.09	63.30±0.26[a]	0.0001	0.0001	0.9900	6.4
	2.5% Ca	58.45±0.57	59.51±0.62	62.10±0.60	64.56±0.65	65.42±0.65	66.21±0.71	67.92±0.73	67.55±0.82	67.27±0.89	64.33±0.23[b]				
	3.5% Ca	59.18±0.58	59.91±0.65	62.82±0.62	64.88±0.64	65.83±0.62	67.43±0.68	67.20±0.69	67.19±0.75	69.26±0.87	64.86±0.23[b]				
	Means	58.42±0.34[a]	59.10±0.38[a]	61.95±0.35[b]	64.34±0.37[c]	65.41±0.39[cd]	66.31±0.42[de]	66.99±0.43[de]	67.07±0.46[de]	67.87±0.55[e]					
Egg surface area (cm^2)	1.5% Ca	73.78±0.53	73.87±0.62	77.24±0.52	79.48±0.56	80.58±0.64	80.98±0.66	81.51±0.70	81.79±0.70	82.42±0.93	79.07±0.22[a]	0.0001	0.0001	0.9823	4.4
	2.5% Ca	74.93±0.49	75.79±0.53	78.17±0.51	80.37±0.56	81.09±0.55	81.85±0.61	83.32±0.63	82.94±0.70	82.66±0.76	80.12±0.20[b]				
	3.5% Ca	75.62±0.50	76.20±0.56	78.79±0.53	80.60±0.55	81.48±0.53	82.76±0.58	82.69±0.59	82.67±0.64	84.40±0.74	80.58±0.19[b]				
	Means	74.77±0.29[a]	75.29±0.33[a]	78.07±0.30[b]	80.15±0.32[c]	81.05±0.33[cd]	81.86±0.36[de]	82.51±0.37[de]	82.47±0.39[de]	83.16±0.47[e]					
Shell percentage (%)	1.5% Ca	8.17±0.09[a]	7.95±0.11[a]	9.01±0.09[a]	8.82±0.10[a]	8.60±0.11[a]	8.78±0.12[a]	8.91±0.12[a]	8.50±0.12[a]	8.62±0.16[a]		0.0001	0.0001	0.0001	7.0
	2.5% Ca	8.90±0.09[a]	8.77±0.09[b]	8.85±0.09[a]	8.90±0.10[a]	8.82±0.10[a]	8.94±0.11[a]	8.94±0.11[a]	8.85±0.12[a]	8.80±0.13[a]					
	3.5% Ca	8.96±0.09[a]	8.83±0.10[a]	8.86±0.09[a]	8.81±0.10[a]	8.87±0.09[a]	8.74±0.10[a]	8.91±0.10[a]	8.89±0.11[a]	8.82±0.13[a]					
SWUSA[1] (mg/cm^2)	1.5% Ca	69.39±0.79[a]	67.55±0.91[a]	77.97±0.77[a]	77.30±0.83[a]	75.82±0.94[a]	77.59±0.98[a]	78.58±1.03[a]	75.36±1.03[a]	76.67±1.38[a]		0.0001	0.0001	0.0001	6.7
	2.5% Ca	76.07±0.72[b]	75.33±0.78[b]	77.04±0.75[a]	78.37±0.83[a]	77.90±082[a]	79.29±0.90[a]	79.53±0.93[a]	78.84±1.03[ab]	78.29±1.13[a]					
	3.5% Ca	76.87±0.74[b]	76.01±0.83[b]	77.02±0.78[a]	77.65±0.81[a]	78.52±0.79[a]	77.63±0.86[a]	79.34±0.87[a]	79.19±0.94[b]	79.25±1.10[a]					
Shell thickness															
Sharp end (mm x 10^{-2}))	1.5% Ca	37.04±0.41[a]	37.57±0.47[a]	41.67±0.40[a]	42.08±0.43[a]	39.87±0.49[a]	39.89±0.51[a]	40.12±0.54[a]	39.13±0.54[a]	39.43±0.72[a]		0.0001	0.0001	0.0001	6.6
	2.5% Ca	40.19±0.37[b]	40.95±0.40[b]	41.77±0.39[a]	42.50±0.43[a]	40.70±0.42[a]	40.44±0.47[a]	41.24±0.48[a]	40.95±0.54[a]	40.40±0.58[a]					
	3.5% Ca	40.73±0.38[b]	41.57±0.43[b]	41.48±0.40[a]	42.41±0.42[a]	40.73±0.41[a]	39.95±0.45[a]	40.65±0.45[a]	40.82±0.49[a]	40.73±0.57[a]					
Equator (mm x 10^{-2})	1.5% Ca	36.29±0.39[a]	36.72±0.45[a]	40.68±0.38[a]	41.24±0.41[a]	38.99±0.46[a]	39.26±0.48[a]	40.26±0.51[a]	38.95±0.51[a]	39.44±0.68[a]		0.0001	0.0001	0.0001	6.3
	2.5% Ca	39.51±0.35[b]	40.39±0.38[b]	40.95±0.37[a]	41.94±0.41[a]	40.38±0.40[b]	39.79±0.44[a]	40.65±0.45[a]	40.73±0.51[b]	40.29±0.55[a]					
	3.5% Ca	40.00±0.36[b]	40.82±0.41[b]	40.84±0.38[a]	41.75±0.40[a]	40.09±0.39[a] b	39.40±0.42[a]	40.71±0.43[a]	40.53±0.46[ab]	40.55±0.54[a]					
Broad end (mm x 10^{-2})	1.5% Ca	36.03±0.39[a]	36.50±0.46[a]	40.77±0.39[a]	41.54±0.41[a]	39.10±0.47[a]	39.29±0.49[a]	40.53±0.52[a]	38.75±0.52[a]	39.24±9.69[a]		0.0001	0.0001	0.0001	6.4
	2.5% Ca	39.27±0.36[b]	40.35±0.39[b]	41.10±0.38[a]	42.16±0.41[a]	40.38±0.41[a]	40.25±0.45[a]	40.78±0.46[a]	41.51±0.52[b]	40.93±0.56[a]					
	3.5% Ca	39.82±0.3[b]	40.77±0.41[b]	40.94±0.39[a]	41.92±0.40[a]	39.99±0.39[a]	39.47±0.43[a]	40.97±0.44[a]	40.63±0.47[b]	40.38±0.55[a]					

[1]SWUSA – shell weight per unit surface area. Means with the same letter within a column (treatment) or row (age) are not significantly different for the same variable, where no significant (P>0.05) interaction occurred. Means with the same letter within a row (age) are not significantly different for the same variable, where a significant (P<0.05) interaction occurred.

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Increasing Ca levels from 1.5 to either 2.5 or 3.5% resulted in a greater response of shell thickness. However, it was noted that increasing Ca beyond 2.5% resulted in shell thickness tending to plateau. A significant (P<0.0001) Ca level × age interaction for shell thickness occurred indicating that the influence of dietary Ca on shell thickness varied during different periods. Menge et al. (1977) observed similar results in turkeys. They reported significantly increased beta-backscatter (BBS) counts; indicating increased eggshell thickness and density, which are the principal elements of shell quality. In agreement with these results, Waldroup *et al.* (1974) and Zapata and Gernat (1995) reported no beneficial effects of Ca level on eggshell thickness after feeding caged turkey breeder hens and commercial layers diets containing Ca levels ranging from 2.5 to 3.5%. Nordstrom and Ouster out (1982) stated that in order for shell thickness to increase, shell weight must increase, egg surface area must increase, or a combination of these two changes must occur. In the present study, a combination of these two changes occurred.

In accordance with the results of Sparks (1998), shell thickness in this study tended to decline with flock age (Table 2). Roland (1980) contended that shell thickness decreases with hen age because total shell deposition after the first three months of lay remains fairly constant while eggs continue to increase in size. This causes the shell to be spread thinner, forcing shell quality to decline. Eggshells were significantly (P<0.05) thinner for birds fed 1.5% compared to 2.5 and 3.5% Ca diets at weeks 36 and 39. Thereafter, no statistically significant (P>0.0001) differences were observed with respect to the sharp and broad ends. In the case of the equator, eggshells from birds fed 2.5% Ca diets were significantly (P<0.05) different compared to eggshells from birds on 1.5% Ca diets at 48 and 57 weeks of age. No significant (P>0.05) differences in eggshell thickness were found between 1.5 and 3.5%, and 2.5 and 3.5% Ca diets with respect to the egg's equatorial region. These results confirmed previously reported findings (North and Bell, 1990) that eggshell thickness declines with age.

Regardless of the Ca level in the diet, the egg weight, shell weight and egg contents and egg surface area increased (P<0.05) over time from 36 to 60 weeks of age (Table 2). In the current study, egg weight and shell weight increased by averages of 1.9% and 2.2% per month, respectively. The greatest (P<0.0001) increase was noted from 39 to 45 weeks (Table 2). A tendency for egg weight to decline was observed at 54 and 57 weeks of age.

CONCLUSION

The results of the present study suggest that dietary Ca level of 2.5% (11.9 and 11.45 MJ ME/kg diet) is adequate to support egg production and eggshell quality in broiler breeder hens reared from 36 to 60 weeks of age. There were no beneficial effects of increasing Ca level from 2.5 to 3.5%. The Ca level of 2.5% is close to Ross Breeders recommended level of 2.8% (4-5 g). These results suggest that 2.5% Ca (3.8 g Ca/hen/day) is adequate to support egg production and to improve eggshell quality in broiler breeder hens. Egg production, egg mass, shell percentage and shell thickness declined but other parameters such as egg weight, egg contents, egg surface area, shell weight and SWUSA increased.

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