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Effect of dietary calcium level on egg production and shell quality in broiler breeder hens at peak production

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Abstract

A study was conducted to evaluate the effects of dietary calcium levels on shell quality and egg production of Ross broiler breeder hens from 25 to 35 weeks of age of. One hundred and ninety eight Ross broiler breeder pullets were reared up to 22 weeks on restricted diets with 1.0, 1.5 and 2.0% Ca. The pullets in each experimental diet were further randomly divided into three treatments with 1.5, 2.5 and 3.5% dietary Ca (22 birds per treatment) in a 3 × 3 factorial arrangement. The feeds were isocaloric and isonitrogenous but differed only in the Ca and P contents. 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. Parameters evaluated included egg production, shell weight, shell percentage, SWUSA, egg contents, egg surface area and shell thickness. Dietary treatment had significant ($P<0.0001$) effect on 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 eggshell quality (SWUSA, shell weight, shell percentage and shell thickness) increased ($P<0.0001$) when dietary Ca was increased from 1.5% to 2.5%. However, no significant ($P>0.05$) differences were observed in these variables between 2.5 and 3.5% Ca levels. The present results suggest that increasing Ca level from 1.5 to 2.5% can improve eggshell quality. All the eggshell quality variables increased over time while egg mass and egg production declined. These results support the current Ross Breeders recommended dietary Ca level of 2.8% (4-5 g) to ensure good eggshell quality. Dietary Ca level of 2.5% and Ca intakes (g/hen/day) of 3.9, 3.8 and 3.5 g at weeks 27, 30 and 33 resulted in a good eggshell quality.

Keywords: Calcium, Egg production, Egg weight, Phosphorus, Eggshell quality, 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). Boorman et al. (1985) stated that Ca could be derived directly from the diet in the light whereas it must be mobilised from the skeleton in the dark when the birds do not feed. The skeletal system is intimately involved in Ca storage for eggshell formation. According to Klasing (1998), the amount of dietary Ca required to maximize bone or eggshell mineralisation and strength is greater than that needed for other functions. Therefore, a proper build-up of Ca stores is essential for the maintenance of bone integrity and acceptable shell quality. Although the shell represents no more than 10% of the egg's weight, it is a vital component to protect and contain food contents of the egg until the consumer uses these (Hunton, 1982). According to Roland (1986), the average Ca requirement for eggshell formation within a population of hens is greatest at approximately peak production. The significance of Ca requirements in layers can be determined by the fact that eggshell contains about 94% calcium carbonate, which is equivalent to 2-2.2 grams (g) of Ca (Hopkins et al., 1987; Roland, 1988). Shell thickness and other physical characteristics of the shell such as shell weight per unit surface area (SWUSA) and percent shell (of total egg weight) have been used to describe shell quality (Hunton, 1982). According to Hamilton (1982), the term eggshell quality is often used as a synonym for "shell strength" and denotes the ability of eggshells to withstand applied forces without cracking or breaking. To ensure maximum shell quality, the hens should consume a minimum of 3.75 g Ca/hen/day (Roland, 1986).

According to Ross Breeders (1998, 2001), broiler breeders require 4-5 g Ca per day from first egg throughout laying period. It is suggested (Ross Breeders, 2001) that this requirement could be satisfied by making the change from pre-breeder (1.5% Ca) to breeder (2.8% Ca) diets immediately prior to first egg. However, Summers *et al.* (1976) stated that although absolute intake of Ca and phosphorus will depend on strain of bird, energy level of the diet and environmental temperature, it is not uncommon to see intakes of Ca in excess of 4.5 g and available phosphorus of 0.6 g per day.

As feed intake is restricted in broiler breeder hens and most feed is consumed during the early hours of morning, these hens are likely to be more susceptible to periods of Ca deficiency during shell formation than *ad libitum* fed birds (Farmer et al., 1983). The present study was undertaken to gain additional information on the effects of dietary levels of Ca on shell quality and egg production up to 35 weeks of age of Ross broiler breeder hens selected for faster growth rate and heavier body weight.

Materials and Methods

One hundred and ninety eight Ross broiler breeder pullets were reared up to 22 weeks on restricted diets with 1.0, 1.5 and 2.0% Ca. The pullets in each experimental diet were further randomly divided into three treatments with 1.5, 2.5 and 3.5% dietary Ca (22 birds per treatment). The hens were placed in individual cages within a common room for all treatments. The cages were fitted with feed troughs, water nipples and perches. Following 3-week adjustment period the hens were fed test diets containing 1.5, 2.5 and 3.5% Ca, respectively.

Experimental diets are given in Tables 1 and 2. Pullets were fed pre-breeder diet containing 1.0, 1.5 and 2.0% Ca from 19 to 22 weeks of age. Two types of breeder diets containing 1.5, 2.5 and 3.5% Ca were fed from 23 to 35 weeks of age and these include breeder phase 1 (23 to 34 weeks) and breeder phase 2 which was fed at 35 weeks. The feeds were isocaloric and isonitrogenous but differed only in the Ca and P contents. 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. The hens were photostimulated at 22 weeks of age and received 16 hours of light by week 26. This photoschedule was continued to 60 weeks of age.

Egg numbers were recorded daily and summarised on a weekly basis throughout the experimental period (i.e., 25 to 35 weeks). Abnormal eggs having multiple yolks, shell-less and those with defective shells were recorded for production calculations. Cumulative egg production was calculated on a per bird basis throughout the experimental period. First egg laid was considered as age at point of lay while flock attaining maximum percent lay on any day and/or week was considered as peak percent lay and the day was regarded as age at peak of lay (Ali et al., 2003). Percent lay on daily basis was calculated using the formula given by North and Bell (1990).

Table 1: Physical composition of laying diets on air dry basis (%)

	Pre-breeder diet		Breeder Phase 1		Breeder Phase 2		Breeder Phase 3	
	1.5% Ca	3.5% Ca	1.5% Ca	3.5% Ca	1.5% Ca	3.5% Ca	1.5% Ca	3.5% Ca
Maize	63.54	63.51	61.92	59.66	63.11	60.81	56.43	62.23
Pollard Glutten	-	-	4.45	2.3	1.8	1.0	-	-
Wheat bran	12.65	6.65	5.15	-	6.55	-	14.90	1.00
Full fat soya	-	-	-	10.0	-	9.95	-	1.70
Soybean oil cake	7.75	11.4	8.6	10.3	8.4	7.55	8.75	9.50
Sunflower oil cake	12.45	11.1	15.0	7.75	15.0	10.00	15.00	15.0
Calcium carbonate (grit)	-	-	2.0	6.15	2.3	6.75	2.25	6.60
Calcium carbonate (fine)	1.15	2.2	0.5	1.5	0.6	1.65	0.6	1.65
Mono calcium phosphate	1.49	4.25	1.29	1.36	1.40	1.50	1.28	1.53
Salt	0.24	0.26	0.41	0.40	0.43	0.44	0.44	0.44
Bicarbonate	0.20	0.15	-	-	-	-	-	-
Choline liquid	0.04	0.04	0.03	0.03	-	0.03	-	-
Lysine	0.10	0.04	0.15	-	0.10		0.03	0.03
Methionine	0.05	0.05	0.005	0.06	0.01	0.05	0.01	0.02
Trace mineral/vitamin premix	0.35	0.35	0.50	0.50	0.30	0.30	0.30	0.30

Table 2: Nutrient composition of experimental diets on air dry basis (%)

	Pre-breeder diet		Breeder phase 1		Breeder phase 2		Breeder phase 3	
	1.0% Ca	2.0% Ca	1.5% Ca	3.5% Ca	1.5% Ca	3.5% Ca	1.5% Ca	3.5% Ca
Moisture	11.07	10.37	10.58	9.96	9.77	9.10	9.85	9.19
Metabolisable Energy (MJ/kg)	11.96	11.70	12.09	12.00.	11.94	11.87	11.46	11.43
Protein	15.22	15.50	18.33	17.72	17.03	16.77	16.68	16.06
Crude fat	3.30	3.06	3.00	4.20	2.97	4.07	3.09	2.98
Crude fibre	7.01	5.99	0.00	0.00	6.65	5.08	8.28	6.64
Ash			6.21	11.23	6.74	12.05	6.90	11.98
Calcium	1.00	2.01	1.51	3.50	1.52	3.50	1.59	3.46
Phosphorus	0.84	1.37	0.78	0.71	0.80	0.74	0.84	0.78
Available phosphorus	0.45	0.90	0.41	0.40	0.43	0.43	0.43	0.54
Arginine	0.98	1.01	1.11	1.12	1.08	1.09	1.10	1.07
Isoleucine	0.60	0.64	0.74	0.76	0.69	0.71	0.67	0.67
Lysine			0.81	0.83	0.76	0.78	0.73	0.72
Methionine	0.35	0.34	0.38	0.38	0.35	0.36	0.33	0.33
TSAA[1]	0.06	0.64	0.73	0.70	0.68	0.67	0.66	0.64
Threonine	0.55	0.57	0.66	0.66	0.62	0.63	0.61	0.60
Tryptophan	0.17	0.18	0.19	0.20	0.18	0.19	0.19	0.18
TA[2] Arginine	0.91	0.93	1.04	1.04	0.99	1.01	1.01	0.99
TA[2] Isoleucine	0.54	0.57	0.67	0.69	0.62	0.65	0.59	0.60
TA[2] Lysine	0.60	0.60	0.70	0.71	0.64	0.67	0.61	0.61
TA[2] Methionine	0.31	0.31	0.34	0.35	0.31	0.33	0.29	0.30
TA[2] TSAA	0.57	0.57	0.64	0.63	0.59	0.60	0.57	0.56
TA[2] Threonine	0.48	0.50	0.59	0.59	0.55	0.56	0.26	0.53
TA[2] Tryptophan	0.15	0.16	0.17	0.18	0.17	0.17	0.17	0.17
AC:Linoleic acid	1.83	1.68	1.65	2.32	1.65	2.26	1.71	1.64
Xanthophylls			23.51	17.68	17.12	14.66	11.29	12.45
Salt	0.24	0.27	0.42	0.41	0.44	0.44	0.45	0.45
Choline	1300.01	1309.56	1205.18	1204.08	1008.79	1003.18	1087.10	993.06
Sodium	0.16	0.16	0.18	0.18	0.19	0.20	0.20	0.20
Chlorine	0.22	0.57	0.33	0.29	0.33	0.31	0.32	0.32
Potassium	0.60	0.60	0.60	0.63	0.63	0.63	0.71	0.61
Magnesium			0.22	0.20	0.23	0.21	0.25	0.23
Manganese			46.82	63.94	50.82	68.71	61.84	71.60

[1]Total sulphur amino acids; [2]Chemically determined

Individual egg weights were recorded for all the eggs produced by each hen on daily basis. Eggs with multiple yolks and defective shells were also included in the weight data. Average egg weight per hen was recorded on a weekly basis. 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.). The surface area (cm^2) of each egg was calculated using the formula of Carter (1975a), $3.9782W^{.7056}$, where W is the egg weight in grams.

Three eggs from each hen were used to determine eggshell thickness at 3 weekly intervals (i.e., 27, 30 and 33 weeks of age). The eggs were weighed individually and stored in a cooled room at 5 ^{o}C. Following the measurement of egg weight, each egg was broken and shell thickness and shell weight including membranes determined. The shells were washed under slightly running water to remove adhering albumen (Strong, 1989; Kul and Seker, 2004) and wiped with a paper towel to remove excessive moisture. An eggshell thickness meter sensitive to 0.01 mm was used to measure the shell thickness. Two measurements were made on the broad end, the equator (waist region) and the sharp end of each egg and the average of each of the two measurements calculated (Ikeme et al., 1983; Ehtesham and Chowdhury, 2002). The shells from individual eggs were then placed in crucibles, dried at 60 ^{o}C overnight, and cooled in the dessicator for approximately 30 minutes, thereafter shell weight was recorded. Percentage shell was calculated by dividing dry shell weight by egg weight and multiplying by 100 (Chowdhury and Smith, 2001). The SWUSA (mg/cm^2) was calculated using the formula of Carter (1975b).

Statistical analyses

The effects of Ca level and age on the egg characteristics data during laying period (25 to 35 weeks) were analysed as a 3 x 3 factorial block design in which data from individual birds 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 and eggshell quality (shell thickness, SW, shell percentage, SWUSA, egg surface area and egg contents). The differences between treatment means were separated using Tukey's studentised range (HSD) test.

Results and Discussion

Dietary Ca level had a significant (P<0.0001) effect on hen's daily Ca intake (Table 3). The Ca intake of the hens significantly (P<0.0001) increased as dietary Ca concentration increased from 1.5 to 3.5%. These results are consistent with those of Clunies *et al.* (1992) who reported that Ca intake of Single Comb White Leghorn hens significantly (P<0.05) increased as dietary Ca concentration increased from 2.5 to 3.5%. Average Ca intakes (g/hen/day) of 2.2, 3.7 and 5.3 for the 1.5, 2.5 and 3.5% Ca levels, respectively were recorded during the experimental period. It is suggested that broiler breeders require 4-5 g Ca/hen/day throughout the laying period (Ross Breeders 1998, 2001). The inclusion of approximately 3.0% Ca in the diet of broiler breeders used in the current study would probably supply this requirement (i.e., 4-5 g Ca/hen/day).

Table 3: The effect of dietary calcium level and age on hen's daily calcium intake

Age (weeks)	Dietary level of calcium		
	1.5%	2.5%	3.5%
27	2.21±0.06[a]	3.91±0.06[b]	5.38±0.06[c]
30	2.29±0.06[a]	3.82±0.06[b]	5.45±0.06[c]
33	2.11±0.06[a]	3.47±0.06[b]	4.99±0.06[c]
CV%	12.8		
Significance level (P)			
Treatment	0.0001		
Age	0.0001		
Interaction	0.0178		

[a,b,c]Means within rows with no common superscripts differ significantly (P<0.05).

The hens Ca intake declined (P<0.0001) significantly with age. At 33 weeks of age the Ca intake was significantly (P<0.05) lower compared to 27 and 30 weeks. However, daily Ca intake was not significantly (P<0.05) different at 27 and 33 weeks.

The influence of Ca levels and age during early lay on egg production and egg mass is shown in Figures 1 and 2. Egg production and egg mass were not significantly (P<0.05) different among the experimental diets. There was a 1.6% average production difference (68.63 *vs*. 69.74%) between 1.5% and 3.5% dietary Ca levels. These results are consistent with published reports (Ousterhout, 1980; Keshavarz and Nakajima, 1993) but inconsistent with findings of Ahmad et al. (2003) and Roland et al. (1996). The type of bird (broiler *versus* commercial layers), as well as, bird strain differences (Ross *versus* Bovans) and Ca levels may have contributed to the various results reported in the literature.

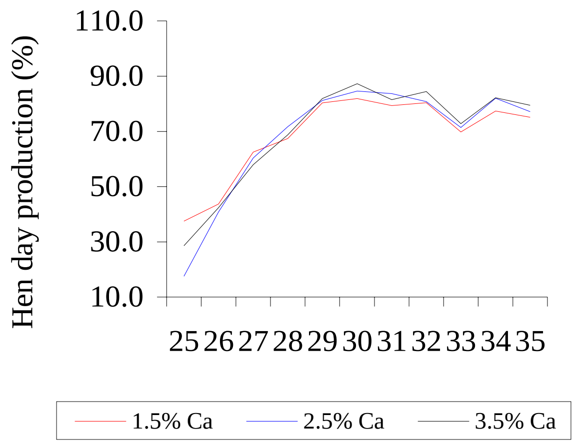

Fig. 1: The effect of dietary Ca levels and age on egg production

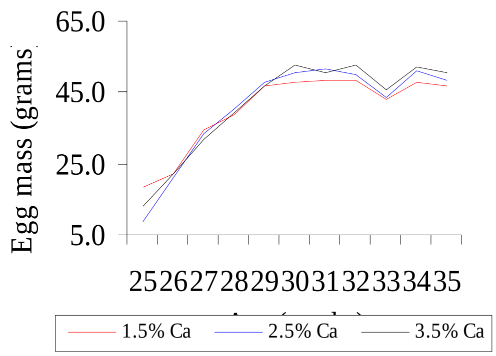

Fig. 2: The effect of dietary Ca levels and age on average egg mass

In the current study, age at point of lay (first time egg was laid) and age at peak of lay were 25 weeks (175 days) and 30 weeks (210 days), respectively. North and Bell (1990) stated that even though today's breeder flocks are best brought into 5% hen-day production at 24 weeks of age, factors such as hatching date, season, strain, temperature, ration and feeding programme may lead to flocks varying 2 or 3 weeks from this age. Ali et al. (2003) reported average age at point of lay and age at peak of lay of broiler breeder hens to be about 24 weeks (164.67 days) and 33 weeks (232.83 days), respectively. In comparison with the results of Ali et al. (2003), the breeder hens in the present study came into lay 1-week late (25 weeks) but reached peak of lay earlier (30 weeks).

Egg production and egg mass significantly (P<0.0001) increased with age up to 30 weeks of age and thereafter declined non-significantly (P>0.05). A sharp decline in egg production and egg mass was noted at 33 weeks of age and this decline could probably be ascribed to among other factors a high ambient temperature (36.7°C), which was 0.4°C higher during this period compared to week 32. Although there is conflicting information in the literature regarding the thermoneutral zone, the accepted general rule of thumb is 20-30°C for layers (Australian Poultry Convention Report, 1985). Additionally, North and Bell (1990) state that normally egg production does not decline until average house temperature reaches 27°C. Barlett (1984) reported that for each 1 °C rise in temperature above the thermoneutral point of around 30 °C, there is a reduction of 1.5 g in feed intake. Reduced consumption renders nutrients such as protein and Ca deficient resulting in low production.

Mortality (includes also culls) rate during this period as calculated per dietary treatments were 4.5, 3.0 and 0% for birds on the 1.5, 2.5 and 3.5% Ca diets, respectively. The fact that mortality declined with increased dietary level suggests that Ca level had an effect on mortality. These results are in disagreement with those of Scott et al. (1999, 2000) who reported no differences in mortality in turkey hens after feeding diets containing Ca levels ranging from 1.24 to 4.5%. No other results on the influence of Ca intake on mortality of broiler breeders could be found in the available literature.

The growth of the broiler chick after hatching is directly related to egg weight. As a general rule, a 1 g change in egg weight results in a 7 to 10 g change in the weight of the 42-day-old finished broiler. In the current study, EW was not significantly (P>.05) different among dietary Ca levels (Table 4). These results are consistent with those of Atteh and Leeson (1983) and Zapata and Gernat (1995) and Ahmad et al. (2003). However, the current results are contradictory to the findings of Summers et al. (1976) who reported linear increase in EW with a higher level of Ca (2.96 *versus* 1.50%).

Age and body weight are the primary factors that influence egg weight. The present results confirm previous observations that egg weight is lowest at the beginning of the production cycle but increases as age and body weight increase throughout the laying period (Leeson and Summers, 1982; McDaniel, 1983). Regardless of Ca level in the diet, the egg weight significantly (P<0.05) increased from week 27 to 35 (Table 5.4). This result is consistent with Reddy et al. (1968) who fed laying hens Ca levels ranging from 2.25 to 5.05%. According to Figure 2, the greatest increases in egg weight were observed during the first 6 weeks of egg production (i.e., from 25 to 30 weeks). Similar results were observed by Yuan et al. (1994).

The mean egg weights for 1.5, 2.5 and 3.5% Ca diets in the current study were 57.76, 58.47 and 58.35 g, respectively. These average weights were slightly higher than the mean egg weight suggested by North and Bell (1990). According to these workers, the minimum egg weight for meat-type birds is between 49.6 and 52.0 g during the first 12 weeks of egg production and after 12 weeks of egg production, respectively. These workers reported that the minimum size is determined by the needs of the hatchery using the eggs and the size of the bird laying the eggs.

Table 4 presents data on egg surface area, SWUSA, egg contents, shell weight, shell percentage and eggshell thickness (sharp end, equator and broad end). Richards and Staley (1967) reported that shell thickness, SW, shell percentage and SWUSA were significantly (P<0.01) correlated with one another.

From the results in Table 4, it is clear that in accordance with egg weight, egg characteristics such as egg surface area and egg contents were not significantly (P>0.05) influenced by dietary Ca levels. However, SWUSA, shell weight, shell percentage and shell thickness improved significantly (P<0.0001) when dietary Ca increased from 1.5 to 2.5%. A further increase in dietary Ca resulted in no (P>0.05) further improvement in these characteristics. These results are inconsistent with those of Clunies et al. (1992) who reported that increasing dietary Ca level from 2.5 to 4.5% significantly (P<0.05) increased shell weight in Single Comb White Leghorn hens. The results on shell thickness are consistent with those of Damron and Flunker (1995) who reported significantly (P<0.01) higher specific gravity (indicating good shell thickness) when Ca level increased from 2.5 to 3.5% in diets of laying hens. A different response in egg quality on increasing Ca levels among breeds is to be expected as breeds differ in weight, frame size, egg production and composition.

In accordance with EW, egg contents and egg surface area significantly (P<0.001) increased with age

Table 4: Effect of calcium level and age on egg weight and egg characteristics

		Age (weeks)				Significance of effect (P)			
Variable	Treatment	27	30	33	Means	Treatment	Age	Interaction	CV
Egg weight (g)	1.5% Ca	56.16 ± 0.74	60.07 ± 0.60	61.49 ± 0.61	59.24 ± 0.38[a]	0.5480	0.0001	0.2274	7.3
	2.5% Ca	56.35 ± 0.75	60.07 ± 0.57	62.97 ± 0.62	59.80 ± 0.38[a]				
	3.5% Ca	55.10 ± 0.73	60.51 ± 0.57	63.39 ± 0.60	59.67 ± 0.37[a]				
	Means	55.87 ± 0.43[a]	60.22 ± 0.33[b]	62.62 ± 0.35[c]					
Egg surface are (cm^2)	1.5% Ca	68.20 ± 0.62	71.54 ± 0.50	72.73 ± 0.51	70.83 ± 0.32[a]	0.5686	0.0001	0.2167	5.2
	2.5% Ca	68.38 ± 0.63	71.54 ± 0.48	73.95 ± 0.52	71.29 ± 0.32[a]				
	3.5% Ca	67.26 ± 0.62	71.88 ± 0.48	74.29 ± 0.50	71.14 ± 0.31[a]				
	Means	67.95 ± 0.36[a]	71.65 ± 0.28[b]	73.66 ± 0.29[c]					
SWUSA[1] (mg/cm^2)	1.5% Ca	73.56 ± 1.02	72.20 ± 0.82	69.48 ± 0.84	71.75 ± 0.52[a]	0.0001	0.0015	0.1731	8.0
	2.5% Ca	76.82 ± 1.03	78.13 ± 0.78	75.11 ± 0.84	76.69 ± 0.51[b]				
	3.5% Ca	75.99 ± 1.00	77.53 ± 0.78	76.27 ± 0.82	76.60 ± 0.50[b]				
	Means	75.46 ± 0.59[b]	75.95 ± 0.46[b]	73.62 ± 0.48[a]					
Egg contents (g)	1.5% Ca	51.14 ± 0.70	54.90 ± 0.56	56.44 ± 0.57	54.16 ± 0.35[a]	0.9399	0.0001	0.3113	7.5
	2.5% Ca	51.10 ± 0.71	54.48 ± 0.53	57.41 ± 0.58	54.33 ± 0.35[a]				
	3.5% Ca	49.98 ± 0.69	54.93 ± 0.54	57.72 ± 0.56	54.24 ± 0.35[a]				
	Means	50.74 ± 0.40[a]	54.77 ± 0.31[b]	57.19 ± 0.33[c]					
Shell weight (g)	1.5% Ca	5.02 ± 0.09[a]	5.16 ± 0.07[a]	5.05 ± 0.07[a]		0.0001	0.0001	0.0365	9.8
	2.5% Ca	5.26 ± 0.09[a]	5.59 ± 0.07[b]	5.55 ± 0.07[b]					
	3.5% Ca	5.12 ± 0.09[a]	5.57 ± 0.07[b]	5.67 ± 0.07[b]					
Shell percentage (%)	1.5% Ca	8.95 ± 0.12	8.61 ± 0.10	8.23 ± 0.10	8.59 ± 0.06[a]	0.0001	0.0001	0.3962	8.1
	2.5% Ca	9.33 ± 0.13	9.32 ± 0.09	8.83 ± 0.10	9.16 ± 0.06[b]				
	3.5% Ca	9.30 ± 0.12	9.23 ± 0.09	8.95 ± 0.10	9.16 ± 0.06[b]				
	Means	9.19 ± 0.07[bc]	9.05 ± 0.06[c]	8.67 ± 0.06[a]					
Sharp end (mm x 10^{-2})	1.5% Ca	39.32 ± 0.48[a]	38.60 ± 0.39[a]	37.00 ± 0.39[a]		0.0001	0.0007	0.01337	7.3
	2.5% Ca	40.59 ± 0.50[a]	41.32 ± 0.38[b]	39.86 ± 0.41[b]					
	3.5% Ca	39.66 ± 0.49[a]	41.09 ± 0.38[b]	40.46 ± 0.39[b]					
Equator (mm x 10^{-2})	1.5% Ca	38.63 ± 0.49	37.71 ± 0.40	36.46 ± 0.40	37.60 ± 0.25[a]	0.0001	0.0023	0.0707	7.5
	2.5% Ca	39.59 ± 0.50	40.58 ± 0.38	39.17 ± 0.41	39.78 ± 0.25[b]				
	3.5% Ca	39.43 ± 0.49	40.23 ± 0.38	39.56 ± 0.40	38.74 ± 0.25[b]				
	Means	39.22 ± 0.29[ab]	39.51 ± 0.0.22[b]	38.40 ± 0.23[a]					
Broad end (mm x 10^{-2})	1.5% Ca	38.71 ± 0.48	37.97 ± 0.39	36.10 ± 0.40	37.59 ± 0.25[a]	0.0001	0.0001	0.0842	7.4
	2.5% Ca	40.02 ± 0.50	40.83 ± 0.37	39.03 ± 0.40	39.96 ± 0.25[b]				
	3.5% Ca	39.70 ± 0.49	40.49 ± 0.38	39.46 ± 0.39	39.88 ± 0.25[b]				
	Means	39.47 ± 0.28[b]	39.76 ± 0.22[b]	38.20 ± 0.23[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.

(Table 4). The increase in egg contents could be attributed mainly to the increase in egg yolk and to some extent increases in egg size. Egg surface area increased at a constant rate from 25 to 28 weeks of age and thereafter increased at a decreasing rate up to the end of the test period. Again, the greatest increase was observed during the first 6 weeks of lay indicating that egg surface area is positively correlated to egg weight.

Eggshell thickness, shell percentage and SWUSA significantly ($P<0.0001$) declined with age. The SWUSA was significantly ($P<0.05$) lower at 33 weeks of age compared to 27 and 30 weeks (Table 4). The decline in SWUSA could be associated with an increased egg weight, which is negatively correlated with shell weight. These results confirmed previous reports that eggshell thickness declines with age. Roland (1980) contended that shell thickness decreases with hen age because total shell deposition after the first 3 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. A significant ($P<0.0001$) Ca level × age interaction for eggshell weight occurred. With the exception of 1.5% dietary Ca level, eggshell weight increased significantly ($P<0.0001$) from 27 to 30 weeks of age. A further increase in age (30 to 33 weeks) did not influence eggshell weight significantly ($P>0.05$).

As expected, eggshell weight was significantly ($P<0.05$) lower at 27 weeks of age compared to the advancing weeks (Table 4). The lower eggshell weight at 27 weeks of age could be attributable to the fact that smaller eggs are produced at the beginning of laying period'; hence lower eggshell weight during this period. Eggshell percentage declined non-significantly by 1.6% and 4.1% between 27 and 30 weeks, and significantly between 30 and 33 weeks, respectively. The 4.1% decline in eggshell percentage from 30 to 33 weeks could be associated with peak production and an increase in egg size. North and Bell (1990) contended that as eggs get larger during the laying period the shells become thinner to cover the larger egg contents. Another possible contributory factor to thinner shells is the decline of Ca from the medullary bone with age. The result on eggshell percentages is consistent with recent findings of Kul and Seker (2004) who reported that shell percentage decreases with increased egg weight. The results of the present study therefore confirmed the view that eggshell percentage is negatively correlated with EW.

The results of the present study suggest that increasing Ca level from 1.5 to 2.5% can improve eggshell quality as determined by eggshell weight, SWUSA, percentage shell and shell thickness. Ross Breeders (2001) recommended slightly higher level of 2.8% Ca in the diet. Shell weight, percentage shell, shell thickness and SWUSA declined with age while egg weight, egg surface area and egg contents increased with age. The decline in the first four factors is probably ascribable to a concomitant decline in the hens' Ca intake as they grow older. The results of the present study support the current recommended dietary level of 2.8% Ca (4-5 g) to ensure good eggshell quality. A Ca level of 2.5% and Ca intakes (g/hen/day) of 3.9, 3.8 and 3.5 g at weeks 27, 30 and 33 resulted in a good eggshell quality.

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