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Effect of dietary calcium intake on its retention by caged broiler breeder hens

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Abstract

Calcium is an important mineral in bone development and egg shell formation of broiler breeder hens. A study was undertaken to further examine the effect of dietary calcium intake on calcium retention of broiler breeder hens and to investigate the relationship between calcium retention and egg characteristics. Ninety broiler breeder hens were obtained from a previous study and allocated to three dietary treatments, 1.5, 2.5 and 3.5% calcium level. Feeds were isocaloric and isonitrogenous but differed only in calcium and phosphorus contents. Birds were fed and caged individually with metal trays placed below cages for excreta collection. Excreta samples (30 birds per treatment) were collected for calcium and phosphorus determinations during a 7-day period at 3-weekly intervals, i.e., 27, 33, 36 and 42 weeks of age. Other parameters measured included calcium intake of hens, hen day production, egg mass, egg weight, shell weight, shell percentage, shell thickness, egg surface area, shell weight per unit surface area, total calcium retention, shell calcium excretion, shell calcium as a percentage of calcium intake and faecal calcium as percentage of calcium intake. These results showed that dietary calcium level had significant ($P<.0001$) effect on calcium intake and retention. Dietary calcium level had significant effect on all parameters except egg weight and shell calcium excretion as a percentage of calcium intake. Calcium retention of hens was correlated with age, calcium intake and eggshell characteristics. Age was significantly correlated with all traits except daily calcium intake, calcium retention and shell percentage. The net effect of calcium intake and total calcium excretion was that the 2.5% calcium level (3.8 g calcium /hen/day) exhibit a significant ($P<.05$) higher calcium retention compared to 1.5% calcium level. This suggests that the calcium level of 2.5% and intake of 3.8 g/hen/day is adequate to support egg production, good shell quality and sufficient bone formation in broiler breeder hens.

Key words: Broiler Breeder Hens, Calcium Intake, Calcium Retention

Introduction

In broiler breeders calcium (Ca) is usually associated with eggshell formation, but Ca has many functions in the body (Turner, 2009). For example, Ca is necessary for the formation and maintenance of the skeleton, muscle contraction and conduction of nerve impulses. The formation of eggshells relies on both dietary Ca and medullary bone reserves. According to Narushin and Romanov (2002), the eggshell performs a double function during embryo development. It has to be thick and strong enough to protect the embryo from external insults. At the same time, the shell should be sufficiently thin and fragile not to act as a strong barrier to the hatching process.

The Ca metabolism in laying hens is most intensive due to high Ca content of eggs (Simons, 1986). For example, eggshells contain 2-0-2.2 g Ca; hence, with increasing egg production, layers require more Ca. The Ca content of the eggshell has been taken as 373 mg/g (Simkiss (1961) as cited by Summers et al. (1976)). The workers stated that there is an increase in Ca retention approximately two weeks before the onset of egg production. This increase is associated with the appearance of the medullary bone in the bone marrow cavities of certain bones. The increased Ca retention is assumed to occur as the hen prepares for the marked output of Ca in the form of eggshell, which occurs during a normal laying cycle (Summers et al., 1976).

Keshavarz and Nakajima (1993) reported significantly ($P<.05$) increased Ca intake with increasing dietary level of Ca and reduced percentage retention of Ca with increases in the Ca intake of laying hens aged 20 to 64 weeks. Similar results were reported

by Leeson and Summers (1997). Also, Larsen et al. (2000) reported a higher retention of Ca with medium (0.94%) and high (1.64%) dietary Ca levels in growing pigs. Conversely, a low dietary Ca (0.35%) supply resulted in lower overall Ca retention.

The present study was undertaken to further examine the effect of dietary Ca intake on Ca retention of broiler breeder hens and to investigate the relationship between Ca retention and egg characteristics.

Materials and Methods

Ninety broiler breeder hens which were previously reared on restricted diets with 1.0, 1.5 and 2.5% Ca up to 22 weeks were obtained from an on-going experiment at the University farm. The birds were further randomly allocated to three treatments with 1.5, 2.5 and 3.5% dietary Ca levels (30 birds per treatment) in a 3 x 4 factorial arrangement. The experiment was conducted from 27 to 42 weeks of age. Two types of breeder diets containing 1.5, 2.5 and 3.5% Ca were fed: breeder phase 1 (23 to 34 weeks) and breeder phase 2 (35 to 46 weeks). Experimental diets were isocaloric and isonitrogenous but varied only in Ca and phosphorus (P) contents. Feed was provided in accordance with the breeders' recommendations while water was provided *ad libitum* with feed weighed back on weekly basis. Birds were housed in individual cages with separate feeders with metal trays placed below cages for excreta collection. Ten replicate birds per treatment were used for excreta collection. Hens were subjected to 16 hours of light throughout the test period. Egg production and egg weight were recorded daily.

Eggshell thickness was determined according to the procedures of Kul and Seker (2004). The eggshells from individual eggs were dried overnight in the oven at 60 ^{o}C and cooled in the dessicator for approximately 30 minutes, and weight 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 shell weight per unit surface area (SWUSA) expressed as mg/cm^2 (Wells, 1967).

Chemical analyses

The excreta samples from 90 birds (30 birds per treatment) were collected during a 7-day period at 3-weekly intervals namely 27, 33, 36 and 42 weeks of age. Excreta were collected on metal trays, and transferred into paper bags. Thereafter, excreta were homogenised before taking a representative sample for determination of Ca. The Ca and P content of the excreta and feeds were analysed after a preceding destruction of organic matter content of samples. Approximately 1-gram samples of excreta were ashed in a muffle furnace at 550^{o}C for 16 hours, and digested in 10 mL Nitric acid and 20 mL distilled water before analysis. Calcium was determined by atomic absorption spectrophotometry as described by Association of Official Analytical Chemists (AOAC) (1984). Calcium retention was calculated by subtracting shell Ca, egg contents Ca and faecal Ca from the hens Ca intake. In order to cancel the differences in Ca intake as a factor, Ca retention was also expressed as a percentage of Ca intake. The Ca content of the egg contents (g Ca/bird/day) was calculated by multiplying eggs weighing 50 or 60 g by 0.025 and 0.030, respectively (Simons, 1986). Shell Ca (mg/g) was obtained by multiplying average egg weight (g) by 373 mg/g.

Statistical analyses

Data during the laying period (25 to 60 weeks) were analysed as a 3 x 4 factorial (3 Ca levels *vs*. 4 age periods) in which data from individual birds served as replicates. Data were subjected to ANOVA using the General Linear Models (GLM) procedures of SAS® (SAS Institute, 1996) to assess the effect of dietary Ca level on Ca retention of the broiler breeder hens. The differences between treatment means were separated using Tukey's studentised range test. Correlation analyses were used to determine the relationship between egg production, egg weight, shell weight, egg contents, shell percentage, egg surface area, SWUSA, average shell thickness, age, shell Ca, Ca intake and Ca retention according to the Pearson correlation procedures of SAS® (SAS Institute, 1996).

Results and Discussion

Calcium intake

The results of daily Ca intake and daily excretion of Ca are summarised in Table 1. Dietary Ca level had a significant (P<.0001) effect on Ca intake and Ca retention of hens. As dietary Ca concentration increased from 1.5 to 3.5%, the Ca intake of hens significantly (P<.05) increased accordingly (Table 1). These results are consistent with Clunies *et al.* (1992a) and Clunies and Leeson (1995) who reported increased Ca intake with increased dietary Ca concentration in Single Comb White Leghorn pullets.

Egg and shell weight

Egg weight was not significantly (P>0.05) different among dietary Ca levels (Table 1). This lack of response in egg weight due to dietary Ca levels is in agreement with previous reports (Ahmad et al., 2003; Scott et al., 2000). It seems that the influence of dietary

Table 1: Daily calcium intake, egg weight, shell weight, shell calcium and faecal excretions of hens fed diets varying in calcium concentration

		Age (weeks)					Significance of effect (P)			
Variable	Treatment	27	33	36	42	Means	Treatment	Age	Interaction	CV
Daily Ca intake (g)	1.5% Ca	2.21 ± 0.08	2.12 ± 0.08	2.26 ± 0.08	2.19 ±0.09	2.19 ± 0.04[a]	0.0001	0.0001	0.1120	11.6
	2.5% Ca	3.91 ± 0.08	3.54 ± 0.08	3.89 ± 0.08	3.85 ± 0.08	3.80 ± 0.04[b]				
	3.5% Ca	5.40 ± 0.08	4.91 ± 0.08	5.52 ± 0.08	5.32 ± 0.09	5.29 ± 0.04[c]				
		3.84 ± 0.05[a]	3.52 ±0.05[b]	3.89 ± 0.05[ac]	3.79 ± 0.05[ac]					
Egg weight (g)	1.5% Ca	55.17 ± 0.63	61.33 ± 0.57	62.66 ± 0.61	67.19 ± 0.64	61.59 ± 0.31[a]	0.0628	0.0001	0.2280	7.2
	2.5% Ca	54.65 ± 0.65	62.62 ± 0.56	63.89 ± 0.62	68.22 ± 0.63	62.34 ± 0.31[a]				
	3.5% Ca	54.15 ± 0.61	62.50 ± 0.56	64.82 ± 0.61	68.75 ± 0.64	62.55 ± 0.30[a]				
	Means	54.66 ± 0.36[a]	62.15 ± 0.33[b]	63.79 ± 0.35[c]	68.05 ± 0.37[d]					
Shell weight (g)	1.5% Ca	5.02 ± 0.09[a]	5.05 ± 0.07[a]	5.12 ± 0.08[a]	6.02 ± 0.08[b]		0.0001	0.0001	0.0001	9.2
	2.5% Ca	5.26 ± 0.09[a]	5.55 ± 0.07[a]	5.70 ± 0.07[ab]	6.02 ± 0.07[b]					
	3.5% Ca	5.12 ± 0.09[a]	5.67 ± 0.07[b]	5.81 ± 0.07[bc]	6.07 ± 0.08[c]					
Shell Ca excretion (g)	1.5% Ca	1.87 ± 0.03[a]	1.89 ± 0.03[a]	1.91 ± 0.03[a]	2.24 ± 0.03[b]		0.0001	0.0001	0.0001	9.2
	2.5% Ca	1.96 ± 0.03[a]	2.07 ± 0.03[a]	2.13 ± 0.03[ab]	2.25 ± 0.03[b]					
	3.5% Ca	1.91 ± 0.03[a]	2.11 ± 0.03[b]	2.17 ± 0.03[bc]	2.26 ± 0.03[c]					
Faecal Ca excretion (g)	1.5% Ca	0.34±0.10[a]	0.10±0.10[a]	0.13±0.10[a]	0.26±0.11[a]		0.0001	0.000`	0.0001	43.0
	2.5% Ca	1.30±0.10[b]	0.75±0.10[a]	0.70±0.10[a]	0.67±0.09[a]					
	3.5% Ca	3.28±0.10[b]	3.03±0.10[b]	1.94±0.10[a]	1.55±0.10[a]					
Total Ca excretion (g)	1.5% Ca	2.83±0.09[ab]	2.42±0.08[a]	2.52±0.08[a]	3.21±0.08[b]		0.0001	0.0001	0.0001	9.7
	2.5% Ca	3.99±0.09[a]	3.56±0.08[b]	3.50±0.08[b]	3.78±0.07[ab]					
	3.5% Ca	4.90±0.08[a]	5.04±0.07[a]	4.48±0.07[b]	4.36±0.08[b]					
Calcium retention (g)	1.5% Ca	0.11 ± 0.14[ab]	0.16 ± 0.11[ab]	0.31 ± 0.11[b]	-0.27 ± 0.12[a]		0.0001	0.0001	0.0001	83.3
	2.5% Ca	0.89 ± 0.13[a]	0.83 ± 0.12[a]	1.14 ± 0.11[a]	0.93 ± 0.11[a]					
	3.5% Ca	0.57 ± 0.12[a]	0.02 ± 0.11[b]	1.47 ± 0.11[c]	1.58 ± 0.12[c]					
Faecal Ca as % of Ca intake	1.5% Ca	15.23±2.00[ac]	4.76±1.94[b]	5.52±2.05[b]	12.01±2.13[bc]		0.0001	0.0001	0.0001	35.8
	2.5% Ca	33.28±1.94[a]	21.71±1.97[b]	18.11±1.97[b]	17.47±1.94[b]					
	3.5% Ca	60.88±1.91[a]	61.18±1.94[a]	35.44±2.01[b]	29.20±2.05[b]					
Shell Ca as % of Ca intake	1.5% Ca	83.22±2.29[a]	88.91±1.81[a]	82.75±1.85[a]	96.75±1.89[b]		0.0001	0.0001	0.0007	14.6
	2.5% Ca	50.23±2.15[a]	57.85±1.89[a]	53.98±1.74[a]	58.76±1.71[a]					
	3.5% Ca	34.30±1.98[a]	41.99±1.78[a]	39.77±1.74[a]	43.21±1.99[a]					
Total excreted Ca as % of Ca intake	1.5% Ca	95.96±3.26[a]	93.49±2.58[a]	88.32±2.63[a]	113.38±2.69[b]		0.0001	0.0001	0.0001	14.8
	2.5% Ca	77.83±3.06[a]	77.14±2.69[a]	71.73±2.48[a]	76.09±2.43[a]					
	3.5% Ca	90.15±2.82a[b]	99.71±2.52[b]	74.27±2.48[a]	70.83±2.82[a]					
Ca retained as % of Ca intake	1.5% Ca	4.04±3.26[a]	6.51±2.58[a]	11.68±2.63[a]	-13.38±2.29[b]		0.0001	0.0001	0.0001	86.2
	2.5% Ca	22.17±3.06[a]	22.86±2.69[a]	28.27±2.48[a]	23.91±2.43[a]					
	3.5% Ca	9.85±2.82[b]	0.29±2.52[a]	25.73±2.48[b]	29.17±2.82[b]					

[1]Percent shell Ca as a percentage of Ca intake (shell Ca/Ca intake x 100); Means with the same letter within a column (treatment) or row (age) are not significantly different (P<.05).

Ca level on egg weight differs between the early and later stages of egg production. In contrast with early lay, where Ca level had no significant influence on egg production, significant differences in egg weight due to dietary Ca level were observed from week 36 to 60. None of these studies except that of Clunies et al. (1992b) attempted to separate shell-forming from non shell-forming days. On the non shell-forming days, Clunies et al. (1992b) observed no significant (P>.05) effect of dietary Ca content on absolute Ca and P retention. These results are, however, inconsistent with those of Scott et al. (1999) and Narváez-Solarte et al. (2006) who reported increased egg weight with higher Ca.

Previous study (Clunies et al., 1992a) reported that shell weight increased significantly due to increasing the dietary Ca from 3.5 to 4.5% in a short-term experiment. Increasing dietary Ca from 1.5 to 2.5% significantly (P<.05) improved shell weight only at 33 and 36 weeks of age (Table1). No differences (P>.05) in shell weight were observed as Ca level increased from 2.5 to 3.5%. This is in agreement with Clunies et al. (1992a). Shell weight was, however, not significantly (P>.05) influenced by Ca intake at 27 and 42 weeks of age. As expected, egg weight significantly (P<.0001) increased with age.

Calcium excretion

Dietary Ca had a significant (P<0.0001) effect on shell Ca excretion (Table 1). As dietary Ca concentration increased from 1.5 to 3.5% there was a significant (P<.05) increase in shell Ca excretion. This was in accordance with the significant increase in shell weight. There were no differences (P>.05) in shell weight and shell Ca excretion of hens fed diets containing 2.5 and 3.5% Ca. As dietary Ca concentration increased from 1.5 to 2.5%, shell Ca excretion increased by 6.1%. Smaller increases of less than one percent were noted when dietary Ca increased from 2.5 to 3.5%. Previous results of Hurwitz and Bar (1966) demonstrated that shell Ca excretion increased as dietary Ca increased from 1.7 to 3.7%. Atteh and Leeson (1983) reported that increasing dietary Ca content from 3.0 to 4.2% resulted in a non-significant (P>.05) increase in shell Ca excretion.

The quantity of Ca deposited in the eggs increases slightly as the hen ages. For this reason, it is suggested that the hens Ca requirement increases with age (Roland, 1986). Calcium excretion through the shell significantly (P<.0001) increased with age (Table 1). The results of the present study are in agreement with Roland (1986).

From Table 1, it is clear that dietary Ca had a significant (P<.0001) effect on faecal Ca and total Ca excretions. Increasing the level of Ca in the diet from 1.5 to 3.5% resulted in increased faecal and total Ca excretions. The faecal Ca excretion significantly (P<.0001) declined over time at the 2.5 and 3.5% Ca levels. No clear trend could be detected for total Ca excretion over time.

In an effort to eliminate differences in Ca intake as a factor, Ca excretion and retention were expressed as a percentage of Ca intake. As indicated in Table 1, statistically significant (P<.05) differences were observed when faecal Ca excretion, shell Ca excretion, total Ca excretion and Ca retention were expressed as a percentage of Ca intake of hens. A significant Ca level x age interactions occurred for all these parameters under investigation. It was observed that faecal Ca excretion in relation to intake increased significantly (P<.05) with increasing dietary Ca concentration up to 3.5%. However, shell Ca excretion as a percentage of intake showed the opposite results. This is probably an indication that Ca in the diet was less efficiently utilised for eggshell formation at higher Ca levels. Total Ca excretion as a percentage of intake was at weeks 27 and 33 significantly (P<.0001) lower when 2.5% Ca was included in the diet. At 36 and 42 weeks, less total Ca as a proportion of intake was excreted when the higher Ca levels (2.5% and 3.5%) were included in the diet.

A non-significant (P>.05) influence of age on percentage faecal Ca excretion for birds on 1.5% Ca diets was noted throughout the test period. At the 2.5 and 3.5% Ca levels, the percentage faecal Ca excretion for birds significantly (P<.05) declined with age.

Percentage shell Ca excretion for birds on 2.5 and 3.5% Ca diets remained constant over time, while significantly (P<.05) increasing with age for birds on 1.5% Ca diets. Accordingly, total Ca excreted as a percentage of intake at the 1.5% Ca level at week 42 increased (P<.0001). The opposite results occurred at the 3.5% Ca level.

Calcium retention increased (P<.0001) with increasing dietary Ca levels at weeks 36 and 42 (Table 1). From Table 1, it is however evident, that percentage Ca retention increased and/or was significantly (P<.05) higher at the 2.5% Ca level. Leeson and Summers (1997) found that percentage Ca retention increases with increased dietary Ca level. These results demonstrated that feeding the 2.5% Ca diet resulted in greater percentage of Ca retained by the hens. This suggests that this level supplied enough Ca to support egg production, good shell quality and bone formation. In disagreement with these results, Qin and Klandorf (1991) and Summers et al. (1976) reported much higher Ca retention for the low Ca diet (1.5%) compared to the high Ca diet (2.96 to 3.5%) in broiler breeder hens and White Leghorn females, respectively. In this regard, Atteh and Leeson (1983) reported a tendency for Ca retention to decline with increasing dietary Ca level. These workers argued that a high retention of Ca is probably associated with a high level of egg production

Table 2: The correlations between age, calcium retention and egg characteristics of broiler breeder hens

Traits	Daily Ca intake	Daily Ca retention	Hen day production	Egg mass	Egg weight	Shell weight	Shell percent	ESA	SWUSA	Shell Ca excretion	Faecal Ca excretion	Average shell thickness
Age	0.01	0.04	0.18**	0.46***	0.65***	0.52***	-0.07	0.66***	0.17**	0.053***	-0.26***	0.27***
Daily Ca intake		0.78***	0.07	0.08	0.01	0.10	0.13*	0.002	0.13*	0.27***	0.50***	0.12
Daily Ca retention			0.13*	0.11	-0.01	-0.04	-0.04	-0.01	-0.05	-0.04	0.38***	-0.06*
Hen day production				0.89***	0.11	0.06	-0.05	0.11	-0.01	0.09	-0.001	0.01
Egg mass					0.52***	0.37***	-0.10	0.52***	0.08	0.35***	-0.06	0.15*
Egg weight						0.71***	-0.18**	1.00***	0.16*	0.58***	-0.11	0.27***
Shell weight							0.55***	0.71***	0.80***	0.74***	0.08	0.83***
Shell percent								-0.19**	0.94***	0.33***	0.25***	0.83***
ESA[1]									0.16**	0.58***	-0.11	0.27***
SWUSA[2]										0.55***	0.21**	0.94***
Shell Ca excretion											-0.05	0.60***
Faecal Ca excretion												0.16**

*P<05; **P<.01; ***P<.0001; [1]Egg surface area (cm^2); [2]Shell weight per unit surface area (mg/cm^2)

and, hence a high Ca requirement. The age of birds and possibly bird strain could have contributed to the differences in the results of the current and previous studies. In a previous study (Qin and Klandorf, 1991) older broiler breeder hens (>60 weeks) were used compared to the current study.

A significant (P<.0001) age effect for percentage total Ca excretion and percentage Ca retention was noted. No clear pattern could, however, be detected with increasing age.

Correlation coefficients

The Ca retention of hens was correlated with age, Ca intake and eggshell characteristics (Table 2). According to Table 2, age was significantly correlated with all traits except daily Ca intake, Ca retention and shell percentage. However, the correlation coefficients were low to moderate (r^2 less than 0.42). These results confirm previous results (North and Bell, 1990) that age is correlated to egg weight and shell thickness. In the current study, age was moderately correlated to egg weight (r^2=0.42) and lowly correlated to shell thickness (r^2=0.08) (Table 2). North and Bell (1990) also found that egg weight is related with chick size and body weight.

Table 2 shows that daily Ca intake was positively correlated to all traits studied except hen day production, egg mass, egg weight, egg surface area, and average shell thickness. In contrast with these results, Ousterhout (1980) reported that egg weight was highly significant and inversely related to dietary Ca level. A moderate correlation (r^2=0.61) was observed between daily Ca intake and Ca retention. This is in agreement with the significant (P<.0001) increase in Ca retention with increasing Ca levels as shown in Table 1.

Statistically significant (P<.01) but a low positive correlation was found between Ca retention and hen day production (r^2=0.04). These results probably indicate that Ca was mainly used for eggshell formation. In this regard, Farmer and Roland (1986) reported a decline in skeletal Ca contribution to the shell as the dietary Ca increases. Likewise, Roland (1986) observed an inverse relationship between skeletal Ca utilisation and availability of dietary Ca.

As indicated in Table 2, hen day production was significantly (r=0.89) correlated with egg mass. The highly significant (P<.0001) correlation (r^2=0.79) between hen day production and egg mass is to be expected as one is a function of the other. This also applies for the low (P<.05) correlation between egg mass (r^2 less than 0.27) and egg weight, shell weight, egg surface area, shell Ca excretion and shell thickness, respectively. Accordingly egg weight was highly significantly (P<.0001) correlated with shell weight (r^2=0.50), egg surface area (r^2=1.00) and shell Ca excretion (r^2=0.50). Kul and Seker (2004) also obtained statistically significant correlation between egg weight, shell weight and average shell thickness. These results and those of Kul and Seker (2004) support a previous report of Stadelman (1989), which showed that shell thickness is directly correlated to egg weight and shell weight. The significant correlation (r^2=0.07) observed in the current study between egg weight and shell thickness is in disagreement with Hunt et al. (1977) who reported a negative correlation (r=-0.037) between these parameters. The differences between current and previous results could be due to species difference, age, strain of birds and dietary Ca contents. According to Baumgartner (1994), genetic correlations between total egg weight and the weights of its component parts are well above 0.5. In this study, these correlations vary from low to high (0.10 to 1.0). The non-significant correlation between egg weight and egg production observed in the current study confirmed the earlier work of McDaniel et al. (1981) in broiler breeders aged 40 and 53 weeks.

Shell weight is significantly influenced by egg weight (Nordstrom and Ousterhout, 1982). These workers found that 47% of variation in shell weight was accounted for by egg weight while a slightly higher value (50%) was obtained in the present study. Roland (1979) explained that this indicated that as a hen lays larger eggs, the amount of the eggshell produced also increases, but not at a rate sufficient to maintain shell thickness.

The moderate to high (r^2=0.50 to 1.0) correlations between shell weight and egg surface area, SWUSA, shell Ca excretion and shell thickness is to be expected, as one is a function of the other. The same applies for the high correlation (r^2=1.0) between egg contents and egg surface area, shell percentage and SWUSA (r^2=0.88), shell percentage and shell thickness (r^2=0.69), as well as, shell Ca excretion and shell thickness (r^2=0.69).

In this study, shell percentage was negatively and lowly correlated (r^2=0.03) to egg weight indicating that as egg weight increased, shell percentage tended to decline. This result confirmed to some extent the findings of Kul and Seker (2004) who studied the external and internal quality traits of eggs in Japanese quail. The results of the current study also support to some extent the view of Roland (1979) who argues that as a hen lays larger eggs, the quantity of the shell produced also increases but not at a sufficient rate to maintain shell thickness.

Richards and Staley (1967) suggested that shell thickness, shell weight, shell percentage and SWUSA, may be classified as shell quality measurements, as these variables are significantly (P<.001) correlated with each other. Accordingly, Richards and Staley (1967) obtained strong relationships among these quality measurements. With the exception of shell

weight and shell percentage (r^2=0.30) a higher level of significance (P<.0001) of these variables was observed in the current study than by Richards and Staley (1967). On the other hand, Pepper *et al*. (1968) found no significant differences in egg weight, shell weight and SWUSA for eggs studied in the last month of the experiment in which Shaver Starcross hens were fed diets containing Ca levels ranging from 3.0 to 6.0%. These workers concluded that failure to show a difference in shell weight or SWUSA would suggest that there is little or no correlation between these measurements of eggshell quality and that of specific gravity (an indicator of shell thickness).

Generally, the thickness of an eggshell depends on the amount or weight of shell present in relation to the egg surface area (Carter, 1975). Nordstrom and Ousterhout (1982) stated that for shell thickness to increase, shell weight must increase, egg surface area must decrease, or a combination of these must occur. The results of the current study are in partial agreement with the findings of Nordstrom and Ousterhout (1982) because of the positive and significant correlations obtained. Unlike in the study of Nordstrom and Ousterhout (1982), egg surface area was not negatively correlated to shell thickness in the current study.

Conclusions

Shell (r=0.27) and faecal (r=0.50) Ca excretions were positively related to Ca intake of layers. Although not calculated, the same relationship was found for Ca intake and faecal Ca excretion as a percentage of intakes. However, the opposite relationship was observed between Ca intake and eggshell Ca excretion as a percentage of intake. Therefore, proportionally less of the Ca intake was used for eggshell formation as the intake of layers increased. The rest of the Ca intake could be utilised for bone formation and/or excreted through the faeces. Therefore, it seems that a higher Ca intake was mainly accompanied by a higher Ca excretion through the faeces.

The net effect of Ca intake and total Ca excretion was that the 2.5% Ca level (3.8 g Ca/hen/day) exhibit a significantly (P<.05) higher Ca retention compared to 1.5% Ca. This Ca level and/or intake appear to be adequate to support egg production, good shell quality and sufficient bone formation in broiler breeder hens. It further seems from the results that daily Ca retention was moderately (r^2=0.61) correlated with daily Ca intake. However, daily Ca retention was not indicative of any egg characteristic.

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