EFFECTS OF DIETARY PROTEIN LEVEL, RESTRICTED FEEDING, STRAIN AND AGE ON EGGSHELL QUALITY IN LAYING HENS

C. W. Kang[1], K. T. Nam[1], O. E. Olson[2] and C. W. Carlson[2]

Animal Resources Research Center, Kon-Kuk University, Kwangjin-Ku, Seoul 143-701, Korea

Summary

The effects of four factors - two dietary protein levels (12 and 16%), feeding methods (*ad libitum* and restricted), strains (A and B), and age of hens - on egg quality and laying performance were examined. Use of the 12% dietary protein level resulted in significantly lower ($p < 0.05$) hen-day egg production, higher feed intake per dozen eggs, and higher Haugh unit scores than the 16% dietary protein level. Reduction of feed intake to about 85% of the *ad libitum* intake decreased mean hen-day production. Significant feeding method-by-age interactions ($F \times A$) were obtained for all parameters. Restricted feeding had favorable effects on shell strength and Haugh unit values after 28 and 16 weeks of egg production, respectively. There was significant difference in shell strength between the two strain. Examination of the three-factor interaction among protein levels, feeding method and strain ($P \times F \times S$) disclosed that the favorable effect of the A strain on shell strength was significant only with the 16% protein-restricted fed group. The other treatment group did show a trend for greater shell strength of the A strain. Mean values for all the parameters examined changed significantly ($p < 0.01$) with the age of hens. Feed intake per dozen eggs tended to increase, with some fluctuation, as the hens aged. There was a linear decrease in Haugh unit scores and shell strength. The effect of restricted feeding on either shell strength or Haugh unit scores were favorable for the aged chickens.

(**Key Words** : Eggshell Quality, Protein, Feeding, Strains, Age)

Introduction

In past decades, development of scientific knowledge of breeding, nutrition and environmentally controlled management have resulted in markedly increased egg production per hen. However, the development of eggshell quality has not kept pace with that of egg production, and economic losses from egg breakage present a serious problem to the poultry industry throughout the world.

One field study conducted in eight northeastern states of U.S.A. showed that shell damage from the hen to the carton reached 12.15% of the eggs produced, and that 50 % of the farms in the states suffered more than 10% of shell breakage (Anonymous, 1975).

Many factors are responsible for the shell damage, including malnutrition, environment, rough handling, age, genetics of hens (Hamilton et al., 1979). It is well accepted that the decline of shell quality as the hen ages is normal and significant. Furthermore, its prevention is considered very difficult. Hens fed adequate diets usually produce eggs with shells of good quality during the first 9 or 10 months of lay (Scott, 1979). Then the shell quality declines to the point where inferior eggshells present a major problem to producers.

Much research has been conducted on the prevention of shell thinning due to age during the past several decades. Some workers have considered juvenescence of old hens and regeneration of their reproductive organs by forced molting. Forced molting has improved shell quality significantly after the molt period (Lee, 1982; Garlich et al., 1984; Castaldo and Maurice, 1988). However, the improvement has not been consistent and has usually disappeared rapidly (Wolford and Tanaka, 1970; Sunde,

[1] Address reprint requests to Dr. C. W. Kang, Animal Resources Research Center, College of Animal Husbandry, Kon-Kuk Univ. 93-1 Mojin-Dong, Kwangjin-Ku, Seoul 143-701, Korea.

[2] Department of Animal and Range Sciences, South Dakota State University, Brookings, SD 57007, U.S.A.

Received February 4, 1996
Accepted August 22, 1996

1971).

The present study was undertaken to determine whether diet alterations that cause a somewhat reduced rate of egg production could influence shell quality.

Materials and Methods

This experiment was designed to examine the effect of reduced egg size and reduced egg production of two strains of laying hens on eggshell quality using limited feed intake and two levels of dietary protein. The experiment consisted of a $2 \times 2 \times 2 \times 20$ factorial arrangement in a randomized block design.

Corn-soy layer diets with two protein levels, 12 and 16%, were prepared (table 1). The diets were fed to the birds in two ways, restricted or *ad libitum*, for 20 periods, each of which consisted of 4 weeks. The *ad libitum* groups were fed diets of two protein levels (12 or 16%). The restricted group on each diet was fed about 85% of the amount of the previous period's feed consumption for the *ad libitum* group.

TABLE 1. COMPOSITION OF EXPERIMENTAL DIETS USED IN TRIAL 2

Ingredients	16% protein layer diet (%)	12% protein layer diet (%)
Corn (ground yellow)	66.0	80.6
Soybean meal, dehulled	20.0	9.0
Alfalfa meal (17% protein)	2.0	2.0
Dicalcium phosphate	2.0	2.0
Limestone	5.0	5.1
Yellow grease	4.0	–
Mineral mix[a]	0.5	0.5
Vitamin mix[b]	0.5	0.5
Methionine	–	0.1
Lysine	–	0.2
Total	100.0	100.0
Calculated analysis		
Crude protein	15.9	12.1
ME_n (kcal/kg)	3,061.2	3,011.6
Calcium[c]	2.64	0.65
Phosphorus	0.65	0.63
Methionine + cystine	0.52	0.52
Lysine	0.80	0.70

[a] Supplied per kg of diet : sodium chloride, 4.8 g; zinc, 18 mg; iron, 10 mg; manganese, 10 mg; magnesium, 7.5 mg; copper, 1.5 mg; cobalt, 0.25 mg and iodine, 0.35 mg.

[b] Supplied per kg of diet : vitamin A, 5280 U.S.P.; vitamin D_3, 1375 U.S.P.; vitamin E, 22 I.U.; vitamin B_{12}, 0.0088 mg; niacin, 44 mg; choline chloride, 440 mg; riboflavin, 6.6 mg; d-calcium pantothenate, 8.8 mg; vitamin K, 1.1 mg; folic acid, 1.1 mg and biotin, 0.11 mg.

[c] For maximum utilization of dietary calcium, calcium content is lower than the NRC requirement.

Two commercial strains of hens, A and B, 20 weeks of age were used. For each strain, 240 pullets were randomly placed in wire cages with three or four birds per cage depending upon sizes of the cages. The cages were located in an environmentally controlled layer house. Five replicates of twelve birds from each strain were assigned to one of four dietary treatments ; 16% protein *ad libitum* (N-16%), 16% protein-restricted feeding (R-16%), 12% protein *ad libitum* (N-12%), and 12% protein-restricted feeding (R-12%).

Egg production was recorded daily. All eggs from each replication laid during the first 5 days of each period were collected and weighed to determine the changes in egg size as hens aged. Five eggs were selected randomly from those used for egg size measurement, and were subjected to albumen height measurement. Albumen quality was determined by mean of the Haugh unit formula.

Shell quality was determined by using the water loaded pressure and droping ball method (Kang et al., 1996). Twelve eggs per replicate from each period throughout the experiment were subjected to shell strengh measurement using the water loaded pressure device. For the first 16 periods, 25 eggs were used for shell quality evaluation using the ball dropper and there after 20 eggs were used.

Data were analyzed statistically by analysis of variance and the Duncan's new multiple-range test (Steel and Torrie, 1960).

Results

The results are summarized in tables 2, 5 and 6. table 3 shows a summary of the analysis of variance for these data.

Dietary protein levels

Protein level influenced hen-day production, feed efficiency, and Haugh units significantly ($p < 0.05$), but did not affect mean egg weight or shell strength as measured by either method (table 2).

The 12% protein level resulted in a decrease of 3.6% in egg production and an increase of 0.255kg of feed consumed per dozen eggs produced. A decrease in either egg production or feed efficiency with suboptimal protein levels in the diet was expected in light of the important

TABLE 2. EFFECTS OF DIETARY PROTEIN LEVELS, RESTRICTED FEEDING AND STRAIN ON LAYING PERFORMANCE, EGG QUALITY AND SHELL STRENGTH

	Protein levels		Feeding method		Strains	
	16%	12%	*Ad libitum*	Restricted feeding	A	B
Hen-day egg production (%)	55.1[a] ± 1.8	51.5[b] ± 1.4	57.6[a] ± 1.9	49.0[b] ± 1.6	53.1 ± 1.2	53.5 ± 1.4
Feed efficiency (kg feed/dozen)	2.044[a] ± 0.07	2.299[b] ± 0.06	2.161 ± 0.04	2.183 ± 0.08	2.208 ± 0.06	2.135 ± 0.08
Haugh units	78.0[a] ± 1.0	80.5[b] ± 0.6	77.9 ± 1.3	80.7 ± 1.6	79.8 ± 0.9	78.9 ± 0.8
Egg weight (g)	63.9 ± 2.3	63.5 ± 1.9	64.0 ± 1.8	63.4 ± 2.1	63.4 ± 2.4	64.1 ± 2.7
Shell breaking strength (kg)*	3.110 ± 0.03	3.114 ± 0.05	3.075 ± 0.04	3.150 ± 0.03	3.169 ± 0.06	3.055 ± 0.05
Shell breaking strength (cm)**	13.16 ± 0.12	13.12 ± 0.16	13.05 ± 0.18	13.23 ± 0.14	13.05 ± 0.14	13.23 ± 0.17

[a,b] Any two means ± SE within a treatment followed by different superscripts are significantly different ($p < 0.05$).
* Water loaded pressure method.
** Dropping ball method.

role of protein in egg production. Further, the protein-by-age interaction (P × A) was highly significant for either egg production or feed conversion (table 3). This suggests that differences in laying performance between the two dietary protein treatments do not remain the some throughout the experimental periods. The significant interaction between protein levels, restricted feeding, strain, and age (P × F × S × A) for hen-day egg production implies that the magnitude of the protein level effects in egg production depends on the other factors.

The mean Haugh unit scores for all other factors were increased 2.5 units by reducing dietary protein levels to 12 % (table 2). The analysis of variance for Haugh unit score did not show any interaction of protein levels with other factors (table 3).

No differences in egg weights between the two different protein level groups (table 2) were noted. The analysis of variance for egg weight (table 3) did not show any interaction of protein levels with other factors.

No significant differences between eggs from hens fed the two different protein levels were noted in mean shell strength using either measuring device. Significant protein × age (P × A), protein × feeding method × strain (P × F × S), and protein level × feeding method × age (P × F × A) interactions were found for shell strength measured with the dropping ball method (table 3). However, this result may have little meaning because of the inconsistency of the dropping ball device in measuring shell strength which will be discussed later.

Feed restriction

The reduction of feed intake of the experimental groups to about 85% of the *ad libitum* intake of the control groups resulted in a decrease of 8.6% in mean hen-day egg production averaged over periods and protein levels (table 2). A significant interaction between protein levels and feeding (P×F) (table 3) was found for egg production. The decrease in egg production of the restricted feeding group was much more severe with the 12% protein diet group (a decrease of 16%) than for the 16% protein diet group (a decrease of 7.4%).

Data presented in table 2, when averaged over all factors, show no effect of feed restriction on the mean values for feed efficiency. Haugh unit scores, egg weight and shell quality. However, significant feeding method-by-age interactions (F×A) were obtained for the laying performance and egg characteristics (table 3).

The effect of feed restriction on shell strength was not significant (table 2). However, the graphical illustration of the feeding-by-age interaction (figure 1) revealed that, with one exception, chickens of the limited feeding group laid eggs with slightly stronger shell than chickens of the *ad libitum* group after 28 weeks (7 periods) of lay. These results suggest that heavy egg production might accelerate the aging of the shell formation mechanism, and thus cause a more rapid decline of shell quality.

TABLE 3. SUMMARY OF VARIANCE FOR LAYING PERFORMANCE AND EGG CHARACTERISTICS

Source	df	Hen-day egg production	Feed efficiency	Haugh unit score	Egg weight	Shell strength	
						Water loading method	Dropping ball method
Total	799						
Protein level (P)	1	*	*	*	—	—	—
Feeding method (F)	1	*	—	—	—	—	—
Strain (S)	1	—	—	—	—	**	—
Age (A)	19	**	**	**	**	**	**
P × F	1	*	**	—	—	—	—
P × S	1	—	—	—	—	—	—
F × S	1	—	—	—	—	—	—
P × A	19	**	**	—	—	—	**
F × A	19	**	**	*	**	**	**
S × A	19	*	—	—	*	—	*
P × F × S	1	—	—	—	—	**	*
P × F × A	19	—	—	—	—	—	*
P × S × A	19	—	—	—	—	—	—
F × S × A	19	—	*	—	—	—	—
P × F × S × A	19	*	—	—	—	—	—

* Statistically significant at $p < 0.05$.
** Statistically significant at $p < 0.01$.

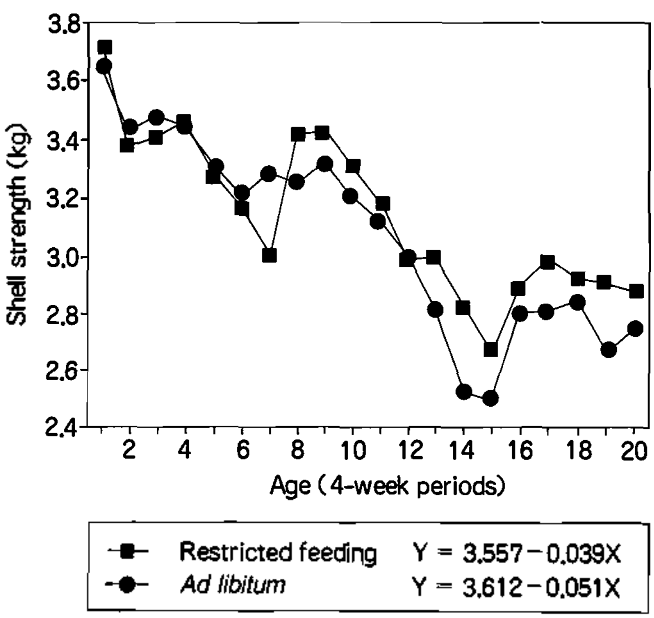

Figure 1. The effect of age on eggshell strength of hens fed *ad libitum* or limited. The shell strength was measured with the water loaded pressure method.

Strain differences

No significant differences were observed between the two strains for egg production, feed efficiency, Haugh unit scores and egg weight when values were averaged over the other factors (table 2).

The strain effect on eggshell quality was found significant only when shell strength was measured using the water loaded pressure method (table 3, figure 2). The mean breaking strength (3.169 kg) of the A strain was significantly higher than that of the B strain (3.055 kg). However, the difference in the mean shell strength between the two strains was not significant when shell strength was determined by means of the dropping ball method.

The three-factor interaction among protein levels, feeding method and strain (P×F×S) for shell strength with the water loaded measurement was highly significant ($p < 0.01$) (table 3). An examination of the P×F×S interaction, as presented in table 4, shows that in general birds of the A strain produced eggs with higher shell quality than those of the B strain. However, statistical analysis disclosed that strain differences within each group

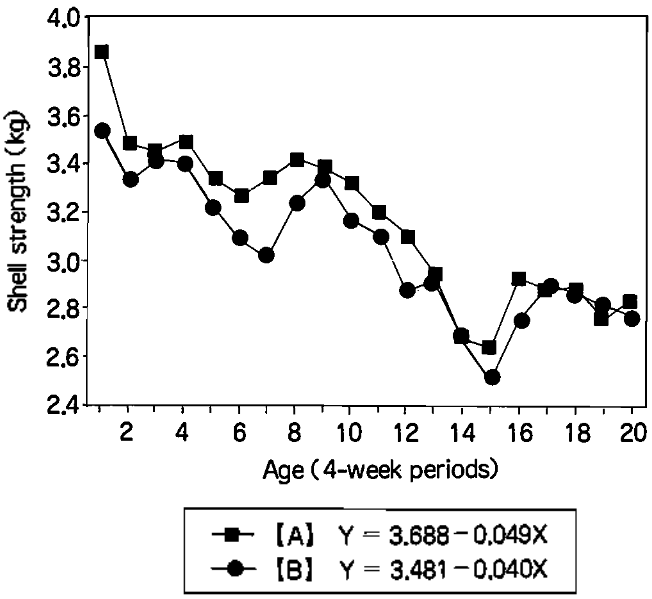

Figure 2. The effect of age on eggshell strength of two strains of hens, A and B, when shell strength was measured with the water loaded pressure method.

TABLE 4. THREE-FACTOR INTERACTION AMONG PROTEIN LEVELS, FEEDING METHOD AND STRAIN FOR SHELL STRENGTH MEASURED WITH THE WATER LOADED PRESSURE DEVICE

Protein	Feeding*	Strain		Simple effect
		A	B	B−A
	N	3.108^{ab}	3.043^{b}	−0.065
16%	R	3.300^{a}	2.990^{b}	−0.310
Simple effect	R−N	+0.192	−0.053	F × S = −0.123
	N	3.107^{ab}	3.039^{b}	−0.068
12%	R	3.160^{ab}	3.149^{ab}	−0.011
Simple effect	R−N	+0.053	−0.110	F × S = +0.029
(N−12%)−(N−16%)		−0.001	−0.004	
(R−12%)−(R−16%)		−0.140	+0.159	

^{a,b} Means followed by different superscripts are significantly different ($p < 0.05$).

* N = hens fed *ad libitum*; R = hens fed restricted.

were not significant except for the R-16% group. Simple effects of either protein levels or feeding methods within strains on shell strength were not significant, when averaged over all the eggs.

Age effect

The rate-of-lay performance and the egg quality traits examined in this experiment and presented in table 5 and 6 have been significantly ($p < 0.01$) influenced by the hen's age (table 3). Average egg production reached its maximum after about 16 weeks of lay, and there after it declined slowly. A significant four-factor interaction among protein levels, feeding method, strain and age indicates that all of the four factors are dependent upon each other in influencing egg production. The feed intake per dozen eggs tended to increase with time, but fluctuated widely. The fluctuations might be in part due to changes in environmental temperature.

TABLE 5. EFFECTS OF HEN'S AGE ON EGG PRODUCTION, FEED EFFICIENCY AND HAUGH UNITS

Age (4-week period)	Hen-day egg production (%)	Feed efficiency (kg feed / dozen)	Haugh units
1	53.7^{bcdef}	1.623^{ghi}	93.9^{a}
2	61.6^{ab}	1.393^{i}	89.1^{ab}
3	61.8^{ab}	1.485^{hi}	86.9^{abc}
4	61.6^{ab}	1.783^{fghi}	89.4^{ab}
5	65.6^{a}	1.903^{efghi}	79.1^{cdef}
6	60.3^{abc}	1.945^{efghi}	81.5^{bcde}
7	57.9^{abcde}	2.510^{abcde}	81.6^{bcde}
8	58.7^{abcd}	2.063^{defghi}	81.2^{bcde}
9	57.3^{abcde}	2.200^{cdefg}	80.6^{bcd}
10	57.4^{abcde}	2.138^{cdefgh}	82.5^{bcd}
11	43.3^{gh}	2.783^{abc}	76.9^{defg}
12	51.9^{def}	2.165^{cdefgh}	81.0^{bcde}
13	52.3^{cdef}	2.365^{bcdef}	75.3^{defg}
14	58.6^{abcd}	1.983^{efghi}	76.7^{defg}
15	50.1^{efg}	1.790^{fghi}	75.3^{defg}
16	49.0^{fg}	2.240^{cdefg}	74.7^{defg}
17	49.9^{efg}	2.305^{bcdefg}	66.1^{h}
18	39.9^{hi}	2.710^{abcd}	73.0^{efgh}
19	35.8^{i}	3.085^{a}	71.1^{fgh}
20	39.5^{hi}	2.978^{ab}	70.0^{gh}

^{a,b,c,d,e,f,g,h,i} Means in the same column with different superscripts are significantly different ($p < 0.05$).

The albumen quality in terms of Haugh unit decreased as the hens aged (figure 3). However, egg weight increased rapidly during the first 20 weeks of lay, and thereafter more slowly (table 6).

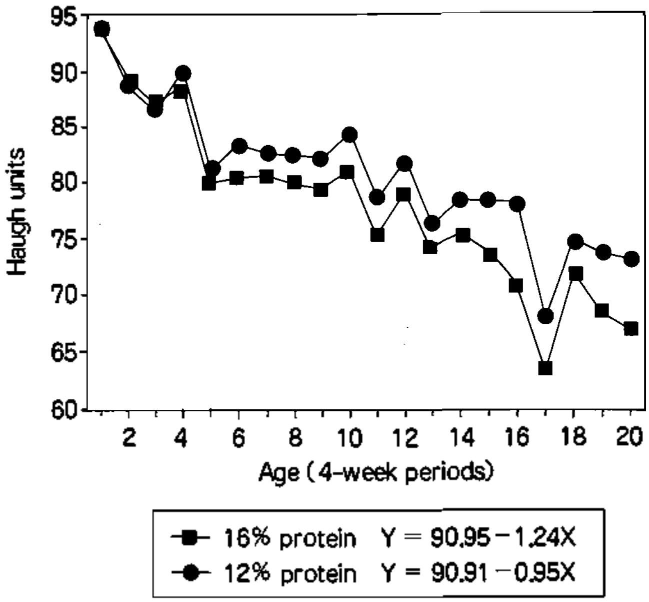

Figure 3. The effect of age on Haugh unit score of eggs produced by hens fed two dietary protein levels (16 and 12%).

TABLE 6. EFFECTS OF HEN'S AGE ON EGG WEIGHT AND SHELL STRENGTH

Age (4-week period)	Egg weight (g)	Shell strength	
		Water loading method (kg)	Dropping ball method (cm)
1	53.6^{j}	3.693^{a}	13.24^{cdef}
2	55.1^{i}	3.415^{b}	12.95^{f}
3	57.6^{h}	3.441^{b}	13.09^{def}
4	59.2^{g}	3.454^{b}	13.33^{bcdef}
5	64.1^{ef}	3.292^{b}	13.25^{cdef}
6	64.2^{ef}	3.189^{c}	13.72^{ab}
7	63.8^{f}	3.189^{c}	13.54^{abc}
8	64.8^{cdef}	3.331^{b}	13.89^{a}
9	65.8^{bcde}	3.371^{b}	13.53^{abcd}
10	66.5^{abc}	3.258^{b}	13.48^{abcde}
11	65.6^{bcde}	3.161^{c}	13.16^{def}
12	65.7^{bcde}	2.995^{cd}	13.03^{ef}
13	66.0^{abcd}	2.941^{de}	12.21^{h}
14	66.4^{abc}	2.692^{fg}	13.34^{bcdef}
15	64.5^{def}	2.590^{g}	12.27^{h}
16	64.9^{cdef}	2.850^{def}	12.53^{gh}
17	65.7^{bcde}	2.898^{def}	13.18^{cdef}
18	66.7^{abc}	2.886^{def}	12.92^{fg}
19	66.3^{abc}	2.790^{def}	12.92^{fg}
20	67.6^{a}	2.814^{def}	13.24^{cdef}

^{a,b,c,d,e,f,g,h,i,j} Means in the same column with different superscripts are significantly different ($p < 0.05$).

Figure 2 shows a trend towards decreasing eggshell strength with age of both strains of birds. According to the estimated linear regression equations, shell strength declined at a rate of 40 g per 4-week periods of the B strain and at a rate of 49 g per 4-weeks for the A strain. The shell thinning progressed sharply after about 8 months of production. The calculated linear regressions accounted for about 80% of the variation.

Discussion

Many studies were conducted using the manipulation of protein level in diet in attempt to reduce egg size for improvement of eggshell quality (Hochreich, 1958; Deaton and Quisenberry, 1965; Smith, 1967; Gardner and Young, 1972; Roland, 1980). These results achieved decreased egg size, but shell quality was not improved. In our result, manipulation of dietary protein level did not affected egg size or egg quality.

The mean Haugh unit scores were increased 2.5 units by reducing dietary protein levels to 12% (table 4). This higher Haugh unit score for the 12% protein treatment than that for the 16% protein treatment is difficult to explain, since so few studies have been done regarding nutritional effects on albumen thickness. Deaton and Quisenberry (1965) obtained lower Haugh unit scores from hens fed a 17% protein diet than from the hens fed a 14% protein diet. Mueller (1956) found no significant differances in Haugh unit score among eggs from hens fed corn-soy, corn-meatscrap, and barley-oat-soy diets. However, a barley-oat-meatscrap diet group exhibited higher Haugh unit scores than the others. They were not able to explain the reasons for the difference.

A significant interaction between protein levels and feeding (P×F) (table 3) was found for egg production. Heywang (1940) restricted feed intake of White Leghorn pullets to 75% and 87.5% of the control group fed on an *ad libitum* basis and reduced egg production, but the restriction did not influence egg size or body weight. On the other hand, Dronawat and McGinnis (1966) reduced egg size by restricting feed intake of White Leghorn layers to 90% of *ad libitum* fed controls. Similar results have been reported by other workers (Polin and Wolford, 1971; Bell and Moreng, 1972). It has been shown that if restricting feed intake decreases egg production it is due to insufficient nutrient intake.

The observation of no significant difference in feed efficiency on feeding method between the treatments is not in agreement with results reported by other researchers (Watking et al., Snetsinger and Zimmerman, 1975; Kari et al., 1977). These workers demonstrated an improvement of feed efficiency by means of limited feed intake. This disagreement appears to be due to variations among experiments in the extent of restriction, methods of limiting feed intake and protein levels of the diet used. As an example, the statistical analysis of the data in this experiment revealed a significant interaction (F×A) for feed efficiency as shown in table 3. Though data did not show, the protein-by-restricted feeding interaction (P×F) indicated that the 12% protein-restricted fed (R-12%) group had a higher feed intake per dozen eggs (2.577 kg/dozen) than the 12% protein-*ad libitum* (N-12%) group (2.180 kg/dozen), but the 16% protein-restricted fed group (R-16%) had a lower feed intake per dozen eggs (2.002 kg/dozen) than the 16% protein-*ad libitum* (N-16%) group (2.131 kg/dozen).

Feeding method-by-age interaction shows no consistent difference in egg weight between the two treatments from the first to fifteenth period, but thereafter the restricted fed groups had a slightly lower mean egg weight than the *ad libitum* groups.

The strain effect on eggshell quality was found only the water loaded pressure method. This inconsistency was felt to be due to large variations in shell strength measurement with the dropping ball method (Kang et al., 1996).

The higher shell strength of the A strain observed in this study is not in accordance with the findings of Potts and Washburn (1974), who obtained opposite results when shell strength was determined for a one-week period after 7 months of lay. This discrepancy might be attributed to changes in shell quality trait in commercial strains with time or the strain by age (S×A) interactions. An examination of data of the current study revealed that for the N-16% group the B strain birds exhibited greater shell strength than the A strain birds for some time during the first 24 weeks of egg production even though after that they consistently produced weaker shelled eggs than the A strain birds.

The albumen quality in terms of Haugh unit decreased as the hens aged (table 5). And interaction between Haugh unit and age illustrated graphically in figure 3. As discussed previously, the 12% protein level had a consistently favorable effect on Haugh unit from the fourth period on. The estimated linear regression equations show that during the course of the experiment Haugh units decreased at a rate of 0.95 per 4-week period for the birds of the 12% protein group, and at a rate of 1.24 for the birds of the 16% protein group. The relationship between age of bird and Haugh unit is essentially linear as shown by the data of Hill et al. (1980). As a general rule of thumb, Haugh unit score declines linearly by approximately 1.5-2.0 units for each month of lay (Cottus and Wilson, 1986). Along with the favorable effect of restriced feeding on albumen thickness, low egg production with the low dietary protein level might reduce somewhat the deterioration in albumen quality. Bearse et al. (1967) observed in their research on forced molting that the extent of improvement in Haugh unit as well as shell quality was influenced by the length of the induced rest. This finding along with the effect of low production on albumen thickness implies that the stress of high egg production might cause a fast decline of egg quality through an acceleration of the aging process of the shell gland.

The decline of eggshell quality along with age is severer in the A than the B strain. Small but significant differences in Haugh unit score and other measures of albumen quality have been found to occur between strains (Fletcher et al., 1981; 1983; Pandey et al., 1984) while strain-flock age interactions have also been shown to be significant but of low magnititude(Hill and Hall, 1980). Figure 1 indicates that a decline of shell strength was greater for the hens fed *ad libitum* than for the hens fed on a limited basis. The shell quality response to feed limiting along with the albumen quality response suggests that physiological stress from heavy egg production may be one of the reasons for a faster breakdown of the reproductive organs involved in producing good quality eggs or shells. The mean values of three parameters, hen-day production, Haugh unit scores and shell strength (kg breaking strength), exhibited a marked decrease after about 8 months of egg production (table 3, 4). The sharp decline might be attributed in part to the stress from a prolonged cage life. Roland et al. (1975a) showed improved egg production, strength of shell and bone by translocating 18-month old hens from the cage to the floor. In addition, increased egg size with age might be the one of the reasons for the deterioration of shell quality in the light of a constant shell weight throughout the production period (Roland et al., 1975b). The reduction of shell strength with increased shell curvature (Carter, 1970) may also be a factor.

Literature Cited

Anonymous. 1975. Egg industry sustains heavy losses from shell damage. Feedstuffs. 47(27):7-31.

Bearse, G. E., R. C. Jennings and T. R. Morris. 1967. The effects of inducing rest in White Leghorn hens with I. C.I. compound 33828. Poultry Sci. 46:1233(abstract).

Bell, D. D. and R. E. Moreng. 1972. Intermittent feeding and lighting of mature Leghorn hens. Poultry Sci.

51:1783(abstract).

Carter, T. C. 1970. Why do egg shells crack? World's Poultry Sci. J. 26:549-561.

Castaldo, D. J. and D. V. Maurice. 1988. Phospholipid content of the chicken shell gland and its relationship to eggshell strength. Poultry Sci. 67:427-433.

Cottus, J. and G. Wilson. 1986. in Egg Quality Handbook, Queensland Department of Primary Industries, Brisbane, Australia. pp. 22-32.

Deaton, J. W. and J. H. Quisenberry. 1965. Effects of dietary protein level on performance of four commercial egg production stocks. Poultry Sci. 44:936-942.

Dronaway, N. S. and J. McGinnis. 1966. Effect of feed restriction and of limiting feeding time for laying hens on egg production, egg size and feed consumption. Poultry Sci. 45:1081(abstract).

Fletcher, D. L., W. M. Britton, G. M. Pesti, A. P. Rahn and S. I. Savage. 1983. The relationship of layer flock age weight on egg component yields and solids content. Poultry Sci. 62:1800-1805.

Fletcher, D. L., W. M. Britton, A. P. Rahn and S. I. Savage. 1981. The influence of layer flock age on egg component yields and solids content. Poultry Sci. 60:983-987.

Gardner, F. A. and L. L. Young. 1972. The influence of dietary protein and energy levels on the protein and lipid content of the hen's egg. Poultry Sci. 51:994-997.

Garlich, J., J. Brake, C. R. Parkhurst, J. P. Thaxton and G. W. Morgan. 1984. Physiological profile of caged layers during one production year, molt, and postmolt : egg production, eggshell quality, liver, femur, and blood parameters. Poultry Sci. 63:339-343.

Hamilton, R. M. G., K. G. Holland, P. W. Voisey and A. A. Grunder. 1979. Relationship between eggshell quality and shell breakage and factors that affect shell breakage in the field-a review. World's Poultry Sci. J. 35:177-190

Heywang, B. W. 1940. The effect of restricted feed intake on egg weight, egg production and body weight. Poultry Sci. 19:29-34.

Hill, A. T. and W. Hall. 1980. Effects of various combinations of oil spraying, washing, sanitizing, storage time, strain, and age of layer upon albumen quality changes in storage and minimum sample sizes required for their measurement. Poultry Sci. 59:2237-2242.

Hill, A. T., R. C. Eissinger, D. M. Hamilton and J. Patko. 1980. Sample sizes required for predicting albumen quality in stored eggs from eight commercial stocks. Can. J. of Anim. Sci. 60:979-989.

Hochreich, H. J., C. R. Douglas, I. H. Kido and R. H. Harms. 1958. The effect of dietary protein and energy levels upon production of Single Comb White Leghorn hens. Poultry Sci. 37:949-953.

Kang, C. W., K. T. Nam, O. E. Olson and C. W. Carlson. 1996. The development of the water loaded pressure method for measuring eggshell quality. AJAS 9:723-726.

Kari, R. R., J. H. Quisenberry and J. S. Bradley. 1977. Egg quality and performance as influenced by restricted feeding of commercial caged layers. Poultry Sci. 56:1914-1919.

Lee, K. 1982. Effects of forced molt period on postmolt performance of leghorn hens. Poultry Sci. 61:1594-1598.

Mueller, W. J. 1956. The influence of energy source, energy-fiber concentration and protein source of the diet on certain egg quality characteristics. Poultry Sci. 35:1074-1078.

Pandey, N. K., C. M. Mahapatra, S. S. Verma, R. C. Goyal and D. C. Johari. 1984. Physical quality traits and components of egg from different strains of White Leghorn hens. Indian J. of Poultry Sci. 19:40-44.

Polin, D. and J. H. Wolford. 1971. Egg production by W. L. adult females restricted in feed intake by limiting their time or allotted amount to eat. Poultry Sci. 50:1618 (abstract).

Potts, L. and K. W. Washburn. 1974. Shell evaluation of white and brown egg strains by deformation, breaking strength, shell thickness and specific gravity. 1. Relationships to egg characteristics. Poultry Sci. 53:1123-1128.

Roland, D. A., SR. 1980. Egg shell quality. 1. Effect of dietary manipulation of protein, amino acid, energy, and calcium in aged hens on egg weight, shell weight, shell quality, and egg production. Poultry Sci. 59:2038-2046.

Roland, D. A., SR., L. O. Rowland, JR. and R. H. Harms, 1975a. Reproductive performance of aged layers translocated from cage to floor. Poultry Sci. 54:912-915.

Roland, D. A., SR., D. R. Sloan and R. H. Harms. 1975b. The ability of hens to maintain calcium deposition in the egg shell and egg yolk as the hen ages. Poultry Sci. 54:1720-1723.

Scott, M. L. 1977. Less phosphorus strengthens bones and eggshells. N. Y. Food and Life Sci. 10:8-11.

Smith, R. E. 1967. The utilization of poultry diets containing high, low and intermediate levels of protein of identical amino acid pattern. Poultry Sci.

46:730-735.

Snetsinger, D. and R. Zimmerman. 1975. Limited feeding of layers. Feedstuffs. 47(4):17-18, 92.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co. Inc., New York.

Sunde, M. L. 1971. What's behind our $60 million egg breakage problem. Farm Tech. 27(1):18-23.

Watkins, M., B. C. Dilworth and E. J. Day. 1973. The effect of calcium source, particle size, level and restricted feeding time on shell strength and production parameters of commercial laying hens. Poultry Sci. 52:2100 (abstract).

Wolford, J. H. and K. Tanaka. 1970. Factors influencing egg shell quality - a review. World's Poultry Sci. J. 26:763-780.