International Journal of Poultry Science 3 (4): 272-278, 2004

Laying Performance and Egg Quality of Hens Supplemented with Sodium Bicarbonate During the Late Laying Period

M.A. Yörük[1], M. Gül[1], A. Hayirli*[1] and M. Karaoglu[2]
[1]Department of Animal Nutrition and Nutritional Disorders, School of Veterinary Medicine, Atatürk University, Erzurum 25700, Turkey
[2]Department of Animal Sciences, College of Agriculture, Atatürk University, Erzurum 25700, Turkey
E-mail: ahayirli@atauni.edu.tr

Abstract: This study was conducted to determine effects of dietary $NaHCO_3$ supplementation on egg production and egg quality during the late laying period. Hisex Brown layers, 54 wks of age, were blocked according to the cage location and then assigned randomly to receive one of four diets containing 0, 0.1, 0.2, or 0.4% $NaHCO_3$ for 75 d. Each diet was replicated in 6 groups; each consisting of 2 cages containing 10 hens. Feed intake (FI) and egg production (EP) were recorded daily and egg weight (EW) was measured bi-weekly. A sample of 12 eggs from each group were collected randomly every 25 d for specific gravity (SG), shape index (SI), shell stiffness (SS), shell thickness (ST), yolk color (YC), albumen index (AI), yolk index (YI) and Haugh unit (HU). The mortality rate (MR) and feed conversion ratio (FCR) were lower, whereas FI, EP and EW were greater for hens fed the experimental diets than those for hens fed the control diet. Moreover, increasing $NaHCO_3$ level linearly decreased MR and FCR, linearly increased EP and EW and quadratically increased FI. Specific gravity and YI for hens fed the experimental diets were lower than for fed the control diet. The diets did not affect SI, SS, ST, YC, AI and HU. However, SG and YI decreased linearly and AI increased linearly with increasing $NaHCO_3$ level. In conclusion, increasing sodium bicarbonate level positively affected laying performance and altered inner egg quality, but did not improve shell quality, during the late laying period in hens.

Key words: Sodium bicarbonate, egg production, egg quality, late laying period

Introduction

Egg production rate decreases and egg weight increases as age advances (Al Bustany and Elwinger, 1987; Summers and Leeson, 1983). Egg quality and composition also change in accordance with level of production and age of layer. As age advances, proportion of yolk increases, whereas proportions of albumen and shell thickness decrease (Akbar *et al*., 1983; Fletcher *et al*., 1983). Despite no difference in feed conversion ratio, hens laying eggs with heavy shell weight have greater egg weight, shell weight and specific gravity than hens laying eggs with light shell weight (Abdullah *et al*., 1994). The frequency of defective eggs may increase from 7 to 11% during laying, collecting and packaging phases of egg production. Both shell thickness and shell stiffness decrease as age advances (Carnarius *et al*., 1996; De Ketelaere *et al*., 2002) because increased demand for Ca deposition to construct eggshell may be compromised (Roland, 1979; 1980)

Elucidation of biochemical and physiological changes occurring during a laying cycle has been focus of numerous studies. Although Ca and P are two major macro-minerals involving bone formation (Frost and Roland, 1991), strength or weakness of eggshell is more directly related to carbonic anhydrase activity than Ca^{+2}-ATPase and calcium-binding protein in shell gland (Balnave *et al*., 1992) and serum Ca concentration (Lennards *et al*., 1981). During shell formation, plasma lactate and pyruvate concentrations and pCO_2 increase sharply; minor changes occur in HCO_3^- concentration, blood gases and osmolality; Na and Cl concentrations decrease; and K, Ca, Mg and glucose concentrations increase in the uterine fluid (Arad *et al*., 1989). Meanwhile, HCO_3^- secreting cells localize towards luminal side, whereas HCl secreting cells localize towards serosal side (Mongin and Carter, 1977). Hens laying shell-less eggs were shown to be hypoxic and hypocapnia and have an increased plasma HCO_3^- concentration from renal sources, not from eggshell during shell formation (Rowlett and Simkiss, 1989). In a radioisotope study, Cipera (1980) showed that the highest ^{14}C activity in shell, albumen and yolk occurred 1, 2 and 4 days after injection of radiolabelled Ca. Moreover, carbonate caused the highest ^{14}Ca activity in shell, amino acids (glycine and leucine) in albumen and glucose and palmitate in yolk, respectively.

In addition to supplementation of macro- and micro-minerals, salt and vitamin D, alteration of acid-base balance by supplementing $NaHCO_3$ (Balnave and Muheereza, 1997; Davison and Wideman, 1992; Grizzle *et al*., 1992) are current approaches for improving laying performance and egg quality. In case of alkalosis, decreased concentration of serum ionized Ca concentration negatively affects shell formation (Odom *et al*., 1986). Also, lower solubility of dietary Ca and slower rate of passage limit the formation of eggshell (Gordon and Roland, 1997). Skeletal and urinary Ca metabolism does not affect eggshell quality (Buss *et al*., 1980; Buss and Guyer, 1984). Although the effects of $NaHCO_3$ supplementation on acid-base status and laying performance during the peak production period have been investigated intensively in layers, data on its impact during the late laying period are limited. The objective of this study was to investigate the effects of increasing level of dietary $NaHCO_3$ supplementation on egg production and egg quality parameters of hens during the late laying period.

Materials and Methods

Animal, diet and management: The Research Animal Ethic Committee of Atatürk University approved this experimental protocol. Two hundreds and forty Hisex Brown layers at age of 54 weeks with uniformity of 94% (the number of hens weighing between 0.9-1.1% of the mean body weight) were selected from the University Research Farm. Hens were blocked according to the location of cages (50x46x46 cm) and then assigned randomly to receives one of four isocaloric and isonitrogenous experimental diets containing 0, 0.1, 0.2, or 0.4% $NaHCO_3$. Each treatment was replicated in 6 groups; each consisting of 2 cages containing 10 hens. The basal diet (Table 1) was formulated to meet or exceed the NRC recommendations (NRC, 1994). In the experimental groups, $NaHCO_3$ was included to the basal diet at expense of wheat bran. During the experiment (75 d), hens were fed ad libitum once daily at 07:30 hours and water was available all the times. Hen house was lit for 17 hours.

Sample collection and analytical procedure: Monthly composites of feed samples were analyzed for DM, CP, NDF, CF and ash contents (AOAC, 1990). Metabolizable energy, Ca and P contents of the diets were calculated from tabular values of feedstuffs for chickens reported by Jurgens (1996). Feed intake and egg production were recorded daily. Before determination of egg weight, a sample of eggs collected bi-weekly were stored for 24 hours in room temperature. Feed conversion ratio was expressed as kilogram of feed intake per kilogram of egg production. A sample of 12 eggs were randomly collected from each experimental group every 25 days to assess egg quality parameters (Ergün *et al*., 1987). Egg quality parameters were specific gravity, shape index, shell stiffness, shell thickness, albumen index, yolk index, yolk color (Yolk Colour Fan, the CIE standard calorimetric system, F. Hoffman-La Roche Ltd., Basel, Switzerland) and Haugh unit.

Statistics: This experiment was arranged in a complete randomized block design. One-way ANOVA was conducted using the Mixed Procedure (SAS, 1998) as repeated measures with time being subplot. The linear model to test the effects of the experimental diets on laying performance and egg quality parameters was as follows:

$$Y_{ijk} = \mu + B_i + TRT_j + T_k + \text{Error A} + (TRT*t)_{jk} + \text{Error B}$$

where Y_{ijk} = response variable, μ = population mean, B_i = block (i = 1 cage at lower level by corridor side to 6 cage at upper level by window side), TRT_j = experimental diet (j = 0 to 4th level of supplemental $NaHCO_3$), T_k = time (k = d or wk relative to initiation of the experiment), Error A = whole plot error, $(TRT*t)_{jk}$ = experimental diet j and time k interaction and Error B = subplot error. Moreover, orthogonal and polynomial contrasts were constructed to compare the mean response variables for hens not supplemented with $NaHCO_3$ versus hens supplemented with $NaHCO_3$ and determine the nature of response variables to increasing level of dietary $NaHCO_3$ supplementation, respectively. Also, Pearson's Correlation coefficients among response variables were determined using the Corr Procedure. The effects of the experimental diets on response variables and correlations among response variables were considered to be significant when probability was equal to or less than 0.05 and tendency towards significance when probability was between 0.05 and 0.10, respectively.

Due to a possibility of differences in airflow and light intensity in the hen house, the linear model included the block effect to eliminate the confounding effect of the location of hens (cages at upper or lower level and/or by window or corridor side) on response variables. Although there was no effect of block factor on any response variables measured, the block factor was not removed from the linear model. However, treatment by interaction term was dropped from the linear model when probability of significance was greater than 0.25. Therefore, unless mentioned below there was no treatment by time interaction effect on laying performance and egg quality variables.

Results and Discussion

Laying performance: The mean mortality rate was lower for hens supplemented with $NaHCO_3$ than for hens not supplemented with $NaHCO_3$ (0.54 vs. 1.14%, $P < 0.006$; Table 2). A decrease in the mortality rate was a linear fashion ($P < 0.01$) and tended to be a quadratic fashion ($P < 0.08$) with increasing level of dietary $NaHCO_3$ supplementation (Table 2). Deaths began to occur 1 month after initiation of the experiment and causes for deaths were not related to infectious diseases. While the mortality rate for hens not supplemented with $NaHCO_3$ was increasing continuously, that for hens supplemented with $NaHCO_3$ remained unchanged as the experiment continued (treatment by time interaction

Table 1: Ingredient and chemical composition of the basal diet

Item	Level, %	Nutrient	Level
Corn	45.00	Dry matter (DM), %	89.10
Soybean meal, 44% CP	21.00	ME, Kcal/kg DM[5]	2530.00
Wheat	7.00		--% of DM--
Barley	3.05	Crude protein	15.59
Wheat bran	9.50	Neutral detergent fiber	30.31
Molasses	2.00	Nitrogen-free extract[6]	37.00
Sunflower oil	1.00	Ether extract	3.57
Limestone	9.50	Ash	13.53
Salt	0.30	Ca[5]	3.86
Lysine	0.10	P[5]	0.61
Methionine	0.10		
Dicalcium phosphate[1]	1.00		
Vitamin-Mineral premix[2]	0.35		
Antioxidant[3]	0.10		
$NaHCO_3$[4]	---		

[1]Per kg contains: Ca, 24% and P, 17.5%.
[2]Per kg contains: Vitamin A, 15.000 IU; cholecalciferol, 1500 ICU, vitamin E (dl-"-tocopheryl acetate), 30 IU; menadione, 5.0 mg; thiamine, 3.0 mg; riboflavin, 6.0 mg; niacin, 20.0 mg; panthotenic acid, 8.0 mg; pyridoxine, 5.0 mg; folic acid, 1.0 mg; vitamin B_{12}, 15 mcg; Mn, 80.0 mg; Zn, 60.0 mg; Fe, 30.0 mg; Cu, 5.0 mg; I, 2.0 mg; and Se, 0.15 mg.
[3]Ethoxyquin.
[4]Obtained from Mersin Soda Sanayii, Mersin 33200, Turkey.
[5]Calculated from tabular values of feedstuffs for chickens (Jurgens, 1996).
[6]Nitrogen-free extract = 100 - (crude protein + neutral detergent fiber + ether extract + ash).

Table 2: The effects of $NaHCO_3$ supplementation on production parameters of hens during the late laying period

	Level of $NaHCO_3$ Supplementation, %					Statistical Contrast, P > F[1]		
Parameter	0	0.1	0.2	0.4	SEM	M	L	Q
Mortality, %[2,3]	1.14	0.77	0.27	0.58	0.29	0.006	0.01	0.08
Feed intake, g[2]	123.88	131.18	127.47	128.39	1.77	0.01	0.22	0.07
Egg production, %[2]	63.73	66.68	68.47	69.38	1.39	0.007	0.003	0.47
Egg weight, g[5]	66.69	69.04	67.68	68.64	0.60	0.01	0.10	0.25
FCR[5]	2.97	2.89	2.78	2.75	0.08	0.07	0.03	0.76

[1]Statistical contrast: M = effect of supplemental $NaHCO_3$, contrasting hens not supplemented with $NaHCO_3$ versus hens supplemented with $NaHCO_3$; L = linear effect of increasing level of $NaHCO_3$ supplementation; Q = quadratic effect of increasing level of $NaHCO_3$ supplementation.
[2]Time effect (P < 0.0001).
[3]Treatment by time interaction effect (P < 0.02).
[4]Time effect (P < 0.004)
[5]FCR = feed conversion ratio (kg feed/kg egg).

effect, P < 0.02). Average mortality rate was fluctuated as the experiment progressed and it was 0.09, 0.11, 1.89, 0.94 and 1.17% on d 15, 30, 45, 60 and 75 relative to initiation of the experiment, respectively (time effect, P < 0.0001). In disagreement with this study, Hayat *et al*. (1999) supplemented broiler chicks 8 and 10g $NaHCO_3$ via drinking water and reported a linear increase in mortality rate, but no adverse effect noted when $NaHCO_3$ was supplemented via feed. Excessive $NaHCO_3$ supplementation in layers is associated with occurrence of metabolic alkalosis, which is metabolically characterized by increased water consumption, plasma Na concentration, urine pH, urinary Na excretion and decreased glomerular filtration rate (Davison and Wideman, 1992). Thus, decreased egg production and increased mortality in response to a high level of $NaHCO_3$ supplementation are attributed to dehydration. Junqueira *et al*. (1984) showed that high level of supplemental $NaHCO_3$ (1.6%) adversely affected egg production, egg quality and the mortality rate and increased blood pH, base excess, HCO_3^- and total CO_2. In this study, although change in the mortality rate was statistically significant, it was within range of the breeder booklet.

Table 3: The effects of $NaHCO_3$ supplementation on egg quality parameters of hens during the late laying period

	Level of $NaHCO_3$ Supplementation, %					Statistical Contrast, $P > F$[1]		
Parameter	0	0.1	0.2	0.4	SEM	M	L	Q
Specific gravity, g/l	1.075	1.076	1.007	1.008	0.001	0.0001	0.0001	0.67
Shape Index, %	77.92	77.36	77.49	77.36	0.41	0.28	0.40	0.60
Shell Stiffness, kg/cm^2	1.17	1.15	1.29	1.21	0.12	0.76	0.64	0.79
Shell thickness, mm	0.367	0.376	0.351	0.369	0.006	0.81	0.44	0.43
Albumen index, %[2,3]	7.74	6.81	9.21	7.87	0.03	0.63	0.04	0.49
Yolk index, %[2,3]	43.21	43.26	37.21	42.33	0.54	0.03	0.0001	0.0001
Yolk color	9.56	9.58	9.61	9.41	0.18	0.89	0.60	0.53
Haugh unit[4,5]	78.98	73.69	80.64	79.46	1.32	0.49	0.15	0.12

[1]Statistical contrast: M = effect of supplemental $NaHCO_3$, contrasting hens not supplemented with $NaHCO_3$ versus hens supplemented with $NaHCO_3$; L = linear effect of increasing level of $NaHCO_3$ supplementation; Q = quadratic effect of increasing level of $NaHCO_3$ supplementation.
[2]Time effect ($P < 0.0001$).
[3]Treatment by time interaction effect ($P < 0.0001$).
[4]Time effect ($P < 0.001$).
[5]Treatment by time interaction effect ($P < 0.10$).

Hens supplemented with $NaHCO_3$ consumed greater amount of feed than hens not supplemented with $NaHCO_3$ (129.0 vs. 123.9g, $P < 0.01$) and feed consumption tended to increase quadratically with increasing level of dietary $NaHCO_3$ supplementation ($P < 0.07$) (Table 2). There was a variation in feed intake during the experimental period ($P < 0.0001$) and average feed intake was 119.6, 119.9, 126.9, 144.1 and 128.1g on d 15, 30, 45, 60 and 75 relative to initiation of the experiment, respectively. Contrasting with the current study, other studies (Balnave and Muheereza, 1997; Grizzle *et al*., 1992) reported that 1% $NaHCO_3$ supplementation did not change feed intake in peak producing layers. However, Fuentes *et al*. (1998) supplemented guinea fowls during the late stage of growing period (from 56 to 84 d of age) with increasing levels of $NaHCO_3$ from 0.6 to 2.4% and reported no changes in feed intake, feed conversion ratio, mortality rate and blood pH.

Hens supplemented with $NaHCO_3$ produced more egg than hens not supplemented with $NaHCO_3$ (68.2 vs. 63.7%, $P < 0.007$) and egg production increased linearly with increasing level of supplemental $NaHCO_3$ ($P < 0.003$; Table 2). Average egg production also changed as the experiment progressed ($P < 0.0001$) and it was 60.8, 64.0, 71.1, 69.0 and 70.4% on d 15, 30, 45, 60 and 75 relative to initiation of the experiment, respectively. The effect of $NaHCO_3$ supplementation on egg production appears to be related to level of supplementation. El-Gammal and Makled (1977) showed that replacing NaCl (0.67%) with $NaHCO_3$ (1%) increased egg production by 6%, whereas increasing $NaHCO_3$ from 1 to 2% decreased egg production by 9%. Also, shell calcium content tended to increase with increasing level of $NaHCO_3$ supplementation. Choi and Han (1983) reported that Na provided as $NaHCO_3$ (1.5%) caused higher egg production in comparing with Na provided as NaCl (1.4%). However, Makled and Charles (1987) reported that 0.5% $NaHCO_3$ supplementation for 16 wks did not affect egg production and feed conversion ratio during the peak period. No change in egg production was also reported in hens supplemented with 1% $NaHCO_3$ during the peak period (Balnave and Muheereza, 1997; Grizzle *et al*., 1992).

Eggs produced by hens supplemented with $NaHCO_3$ were heavier than eggs produced by hens not supplemented with $NaHCO_3$ (67.5 vs. 66.7g, $P < 0.01$; Table 2) and egg weight tended to increase linearly with increasing level of dietary $NaHCO_3$ supplementation ($P < 0.10$; Table 2). Average egg weight fluctuated by time ($P < 0.004$) and it was 68.8, 69.6, 68.0, 66.0 and 67.6g on d 15, 30, 45, 60 and 75 relative to initiation of the experiment, respectively. Egg mass was reported to not change in peak producing hens reared under high ambient temperature when 1.0% $NaHCO_3$ supplemented (Balnave and Muheereza, 1997).

Feed conversion ratio (kg feed consumed per kg egg produced) for hens supplemented with $NaHCO_3$ tended to be lower than hens not supplemented with $NaHCO_3$ (2.81 vs. 2.97, $P < 0.07$) and feed conversion ratio decreased linearly with increasing level of dietary $NaHCO_3$ supplementation ($P < 0.03$) (Table 2). Feed conversion ratio also changed as the experiment advanced ($P < 0.0001$) and it was 2.89, 2.74, 2.64, 3.25 and 2.73 on day 15, 20, 45, 60 and 75 relative to initiation of the experiment, respectively. The effects of $NaHCO_3$ supplementation on feed intake change depending upon the means of delivery and the sources of Na. Hayat *et al*. (1999) supplemented broiler chicks with 2, 8 and 10g $NaHCO_3$ per liter of drinking water. Increasing level of supplemental $NaHCO_3$ via drinking water, but not feed, improved feed conversion ratio. This result

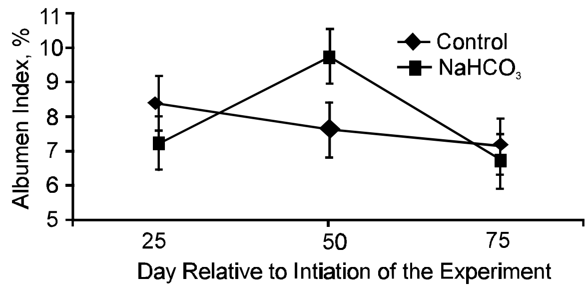

Fig. 1: Effect of $NaHCO_3$ supplementation on albumen index

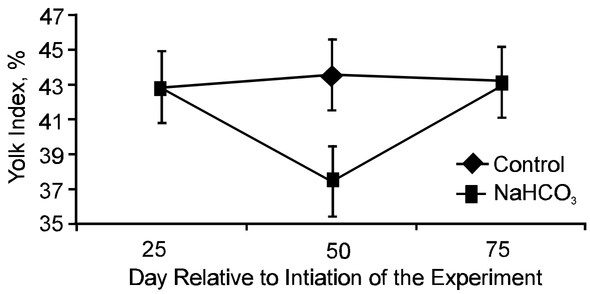

Fig. 2: Effect of $NaHCO_3$ supplementation on yolk index

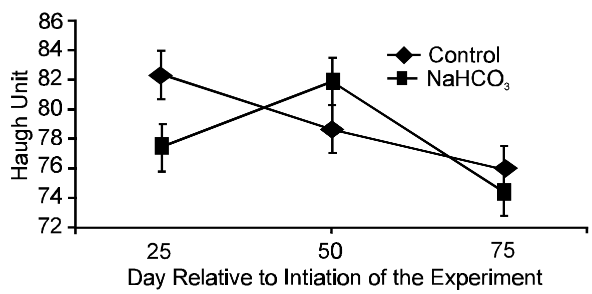

Fig. 3: Effect of $NaHCO_3$ supplementation on Haugh unit.

was also more pronounced when chicks were supplemented with $NaHCO_3$ than they were supplemented with $KHCO_3$, suggesting that sources of bicarbonate affect blood acid-base balance and plasma electrolyte concentrations.

Egg quality: There were neither orthogonal nor polynomial effects of increasing level of $NaHCO_3$ supplementation on shape index (77.5%), shell stiffness (1.21 kg/cm^2), shell thickness (0.37 mm), yolk color (9.54%) and Haugh unit (78.2) (Table 3). Makled and El-Gammal (1997) replaced NaCl with $NaHCO_3$ and increased level of supplemental $NaHCO_3$ and reported that results were inconsistently improved egg quality in different breed of pullets. The authors concluded that 1% supplemental $NaHCO_3$ improved eggshell and internal qualities in the Rhode Island Red, but not in the AR Egypt. However, in other study by Ferguson *et al*. (1974), it was shown that supplementation of $NaHCO_3$ increased Ca retention in legs and increased bone strength in layers. Improvements in eggshell thickness and stiffness in hens supplemented with 0.5% (Makled and Charles, 1987) and 1% $NaHCO_3$ (Balnave and Muheereza, 1997) were also reported. Specific gravity for hens supplemented with $NaHCO_3$ was lower than for hens not supplemented with $NaHCO_3$ (1.030 vs. 1.075 g/l, $P < 0.0001$) and increasing level of dietary $NaHCO_3$ supplementation linearly decreased specific gravity ($P < 0.0001$) (Table 3). In a multifactorial arrangement of treatments, Grizzle *et al*. (1992) reported that 1% $NaHCO_3$ supplementation did not alter specific gravity of eggs in hens provided three different types of lightening program and fed four different sources of Ca. No change in specific gravity was also reported in peak producing hens supplemented with 0.5% $NaHCO_3$ (Makled and Charles, 1987).

Although there was no main effect of $NaHCO_3$, increasing level of dietary $NaHCO_3$ supplementation linearly increased albumen index ($P < 0.04$; Table 3). Albumen index was affected by time and it was 7.6, 9.2 and 6.9% on d 25, 50 and 75 relative to initiation of the experiment ($P < 0.0001$). Lesson and Caston (1997) fed hens diet containing acid-base balance of 150, 200, 250 and 300 mEq/kg and reported no effect on albumen height and thickness. Yolk index for hens supplemented with $NaHCO_3$ was lower than for those not supplemented with $NaHCO_3$ (40.9 vs. 43.2%, $P < 0.03$) and it decreased both linearly ($P < 0.0001$) and quadratically ($P < 0.0001$) with increasing level of dietary $NaHCO_3$ supplementation (Table 3). Yolk index was also affected by time ($P < 0.0001$) and it was 42.7, 38.8 and 43.0% on d 25, 50 and 75 relative to initiation of the experiment. Moreover, there were significant effects of experimental diets by time interaction on albumen index ($P < 0.0001$; Fig. 1) and yolk index ($P < 0.0001$; Fig. 2). As feeding trial progressed, albumen index and yolk index responded differently to supplemental $NaHCO_3$. Negative correlation between albumen index and yolk index ($r = -0.41$, $P < 0.0001$) was in agreement with opposite response to treatment by time interaction effect. Haugh unit tended to respond to supplemental $NaHCO_3$ over time in a similar fashion to albumen index ($P < 0.10$; Fig. 3). Haugh unit was positively correlated with albumen index ($r = 0.86$, $P < 0.0001$). This is not surprising because structure of albumen, one of major determinants for internal quality, is related to Haugh unit (Eisen *et al*., 1962). Haugh unit also fluctuated over time and was it 79.0, 81.3 and 75.0 on d 25, 50 and 75 relative to initiation of the experiment ($P < 0.001$).

In conclusion, during the late laying period, the effects of increasing level of $NaHCO_3$ supplementation on egg production and egg quality parameters were investigated in this study. Increasing level of dietary

$NaHCO_3$ supplementation from 0 to 0.4% linearly decreased mortality rate and feed conversion efficiency and linearly increased feed intake and egg production. However, its effects on egg quality parameters were variable. Supplementation of $NaHCO_3$ may prolong persistency of maintaining a profitable egg production during the late laying period.

References

Abdullah, A.G., R.H. Harms, H.R. Wilson and O. El-Husseiny, 1994. Effect of removing trace minerals from the diet of hens laying with heavy or light shell weight. Poult. Sci., 73: 295-301.

Akbar, M.K., J.S. Gavora, G.W. Friars and R.S. Gowe, 1983. Composition of eggs by commercial size categories effects of genetic group, age and diet. Poult. Sci., 62: 925-933.

Al Bustany, Z. and K. Elwinger, 1987. Shell and interior quality and chemical composition of eggs from hens different strains and ages fed different dietary lysine levels. Acta. Agri. Scand., 37: 175-187.

Arad, Z., U. Eylath, M. Ginsburg and H. Eyal-Giladi, 1989. Changes in uterine fluid composition and acid-base balance status during shell formation in the chicken. Am. J. Physiol., 257: R732-737.

Association of Official Analytical Chemists (AOAC), 1990. Official Methods of Analysis. Vol. I. 15th ed. AOAC, Arlington, VA.

Balnave, D. and S.K. Muheereza, 1997. Improving eggshell quality at high temperatures with dietary sodium bicarbonate. Poult. Sci., 76: 588-593.

Balnave, D., N.U. El-Khatib and D. Zhang, 1992. Calcium and carbonate supply in the shell gland of hens laying eggs with strong and weak shells and during and after a rest from lay. Poult. Sci., 71: 2035-2040.

Buss, E.G. and R.B. Guyer, 1984. Bone parameters of thick and thin eggshell lines of chickens. Comp. Biochem. Physiol., 78: 449-452.

Buss, E.G., P. Merkur and R.B. Guyer, 1980. Urinary excretion of calcium in the presence and absence of shell formation by chickens producing thick or thin shells. Poult. Sci., 59: 885-887.

Carnarius, K.M., K.M. Conrad, M.G. Mast and J.H. Macneil, 1996. Relationship of eggshell ultrastructure and shell strength to the soundness of shell eggs. Poult. Sci., 76: 655-663.

Choi, J.H. and I.K. Han, 1983. Dietary interaction of phosphorus with sodium from either chloride or bicarbonate affects laying hen performance. Poult. Sci., 62: 341-344.

Cipera, J.D., 1980. Source of carbon for the biosynthesis of eggshell carbonate in the hen. Comparison of six 14C labeled compounds as sources of carbon in eggshells, albumen and yolk. Poult. Sci., 59: 1529-1537.

Davison, S. and R.F. Wideman, 1992. Excess sodium bicarbonate in the diet and its effect on Leghorn chickens. Br. Poult. Sci., 33: 859-870.

De Ketelaere, B., T. Govaerts, P. Couke, E. Dewil, J. Visscher, E. Decuypere and J. De Baerdemaeker, 2002. Measuring the Eggshell strength of 6 different genetic strains of laying hens: techniques and comparisons. Br. Poult. Sci., 43: 238-244.

Eisen, E.J., B.B. Bohren and H.E. McKean, 1962. The Haugh unit as a measure of egg albumen quality. Poult. Sci., 41: 1461-1468.

El-Gammal, A.M. and M.N. Makled, 1977. Incorporation of sodium bicarbonate into laying rations. I. Effect on egg production and hatchability. Beitr. Trop. Landwirtsch. Veterinarmed, 15: 173-176.

Ergün, A., S. Yalçin, I. Çolpan, T. Dikicioglu and S. Yildiz, 1987. Utilization of vetch by laying hens. J. Fac. of Vet. Med. Univ. of Ankara, 34: 449-466.

Ferguson, T.M., J.T. Scott, D.H. Miller, J.W. Bradley and C.R. Creger, 1974. Bone strength of caged layers as affected by Portland cement and sodium bicarbonate. Poult. Sci., 53: 303-307.

Fletcher, D.L., W.M. Britton, G.M. Pesti and S.I. Savage, 1983. The relationship of later flock age and egg weight on egg component yields and solid content. Poult. Sci., 62: 1800-1805.

Frost, T.J. and D.A. Roland, Sr., 1991. The influence of various calcium and phosphorus levels on tibia strength and eggshell quality of pullets during peak production. Poult. Sci., 70: 963-969.

Fuentes, M.F., J.F. Zapata, G.B. Espindola, E.R. Freitas, M.G. Santos and F.M. Sousa, 1998. Sodium bicarbonate supplementation in diets for guinea fowl raised at high environmental temperatures. Poult. Sci., 77: 714-717.

Gordon, R.W. and D.A. Roland, Sr., 1997. The influence of environmental temperature on *in vivo* limestone solubilization, feed passage rate and gastrointestinal pH in laying hens. Poult. Sci., 76: 683-688.

Grizzle, J., M. Iheanacho, A. Saxton and J. Broaden, 1992. Nutritional and environmental factors involved in eggshell quality of laying hens. Br. Poult. Sci., 33: 781-794.

Hayat, J., D. Balnave and J. Brake, 1999. Sodium bicarbonate and potassium bicarbonate supplements for broilers can cause poor performance at high temperature. Br. Poult. Sci., 40: 411-418.

Junqueira, O.M., P.T. Costa, R.D. Miles and R.H. Harms, 1984. Interrelationship between sodium chloride, sodium bicarbonate, calcium and phosphorus in laying hen diets. Poult. Sci., 63: 123-130.

Jurgens, M.H, 1996. Animal Feeding and Nutrition, 8th ed. Kendall/Hunt Pub. Co., Dubuque, IA.

Lennards, R., D.A. Roland, Sr. and J.A. McGuire, 1981. The relationship of serum calcium to shell weight and other criteria in hens laying a low or high incidence of shell-less eggs. Poult. Sci., 60: 2501-2505.

Lesson, S. and L.J. Caston, 1997. A problem with characteristics of the thin albumen in laying hens. Poult. Sci., 76: 1332-1336.

Makled, M.N. and A.M. El-Gammal, 1997. Incorporation of sodium bicarbonate into laying rations. I. Effect on egg quality. Beitr. Trop. Landwirtsch. Veterinarmed., 15: 177-183.

Makled, M.N. and O.W. Charles, 1987. Eggshell quality as influenced by sodium bicarbonate, calcium sources and photoperiod. Br. Poult. Sci., 28: 705-712.

Mongin, P. and N.W. Carter, 1977. Studies on the avian shell gland during egg formation: aqueous and electrolyte composition of the mucosa. Br. Poult. Sci., 18: 339-351.

National Research Council (NRC), 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Odom, T.W., P.C. Harrison and W.G. Bottje, 1986. Effects of thermal-induced respiratory alkalosis on blood ionized calcium levels in the domestic hen. Poult. Sci., 65: 570-573.

Roland, D.A., 1979. Factor influencing shell quality of aging hens. Poult. Sci., 58: 774-777.

Roland, D.A., 1980. The ability of young and old hens to change shell deposition with sudden neutral drastic changes in egg size. Poult. Sci., 59: 924-926.

Rowlett, K. and K. Simkiss, 1989. Respiratory gases and acid-base balance in shell-less avian embryos. J. Exp. Biol., 143: 529-536.

Statistical Analysis System (SAS), 1998. SAS® User's Guide: Statistics, Version 7th. SAS Inst. Inc., Cary, NC.

Summers, J.D. and S. Leeson, 1983. Factors influencing early egg size. Poult. Sci., 62: 1155-1159.