Journal of Animal and Feed Sciences 1, 1992, 51–58

Changes in egg shell quality during the first year of laying in hens

Barbara Z. Kamińska and Bogumiła Skraba

Institute of Animal Production, Department of Nutrition and Physiology
Sarego 2, 31-047 Kraków, Poland

(Received 5 November 1991; accepted 29 November 1991)

ABSTRACT

One hundred and four hens of parential stock Astra S were kept in individual cages. Two eggs per hen were taken for analyses at 30, 38, 46, 54 and 62 weeks of hens' age. The total number of 845 eggs were tested.

Shell surface area (SSA) was calculated according to the formula: SSA = egg weight$^{0.667}$ × 4.67, and shell density according to the ratio of weight of dried shell without membranes to SSA. Ca and Mg contents in dried shell without membranes were determined using atomic spectrophotometry absorption methods.

Egg weight increased throughout the laying period, whereas egg shell weight only up to 46 weeks. After 46 weeks shell thickness declined significantly ($P < 0.01$). The highest breakage strength was found at 38 weeks, however, the highest shell density was at 46 and 54 weeks. The highest levels of Ca and Mg in 1 g of shell and their total contents in the shell were at 38 weeks. The Mg:Ca ratio reached the maximum values at 54 weeks.

During the laying period not only the total amont of Ca and Mg in shells was undergoing changes but also the chemical composition of shells. These traits proved to be strictly related to the egg shell breakage strength.

KEY WORDS: egg shell quality, hen, minerals

INTRODUCTION

After having attained the peak of laying by hens, the quality of the egg shell is becoming more important than increasing the weight of the egg. Recently, deterioration of egg shell quality has been observed in many countries. In the USA, for instance, the number of broken eggs in May 1991 amounted to 1224 mln, exceeding by 8% the number reported for May 1990 (Washington Bureau, 1991). This phenomenon results from an attempt to attain high laying performance with little consideration for egg shell quality. Egg shell damage problems have become more noticeable since hens are being kept in battery cages (Oosterwoud, 1987).

The studies by Lewis and Perry (1987), Kamińska (1990) as well as by Skraba and Kamińska (1991) have shown that there are strains in which the egg shell weight increases only up to 44–46 weeks of age, after which it is maintained at the same level while the egg weight keeps increasing. This evidently leads to a reduction of the thickness of the shell and thus to its lesser percentage of the egg weight, both traits being highly correlated with breakage strength.
The aim of this study was to investigate changes occurring during the laying period in the parameters which are regarded as relevant to the egg breakage strength.

MATERIALS AND METHODS

The material for the study included 104 hens of parental stock Astra A, aged 28 to 64 weeks, kept in individual cages. Hens were fed ad libitum, the feed containing 14.5% crude protein and 3.5% Ca. Daily feed intake was about 140 g, which resulted in consumption of about 21 g protein and 4.9 g Ca per day. Daily individual laying and egg weight were recorded.
Egg analyses were made 5 times, viz., at 30, 38, 46, 54 and 62 weeks of hens' age. It was planned to collect two eggs from each hen 3–4 days preceding analysis, however, in practice this was not always possible. That is why the total number of tested eggs was 845. The following parameters were determined: egg weight, weight of fresh shells (after a thorough cleaning from albumen), weight of dried shells without membranes, thickness at 3 points (at sharp and blunt ends and at equator) of fresh shells without membranes, breakage strenght measured by the quasi-static compression technique. Ca and Mg levels in the shell without membranes were determined using atomic spectrophotometry absorption methods in a Carl Zeiss Jena AAS IN apparatus.
The following values were calculated: mean shell thickness, percent of fresh and dried shell, Mg:Ca ratio. Shell surface area was calculated according to the formula recommended by Hugnes (1984) and used by Lewis and Perry (1987) as follows: egg weight$^{0.667} \times 4.67$, and shell density as dried shell weight:shell surface area.

RESULTS

It was found that egg weight increased throughout the whole laying period, whereas egg shell weight only up to 46 weeks, i.e. to the point when the fresh shell accounted for 10.55% and dried shell without membranes – 8.76% of egg weight (Table 1).
Over the period from 30 to 46 weeks the shell thickness was maintained at the same level of ca 379 μm, after which it decreased to a statistically highly significant degree to ca 366 μm at 54 weeks and 356 μm at 62 weeks of hens' age (Table 2).

TABLE 1

Weight of eggs and shell

Age wks	Egg weight (g)	Shell weight (g) fresh	dried	Percent shell fresh	dried
30	51.1^{A}	5.34^{A}	4.41^{Aa}	10.47^{A}	8.65^{AB}
38	56.1^{B}	5.81^{B}	4.79^{Ab}	10.37^{AB}	8.57^{AB}
46	57.7^{C}	6.08^{C}	5.04^{B}	10.55^{A}	8.76^{A}
54	58.6^{CD}	6.02^{BC}	5.00^{B}	10.29^{AB}	8.55^{AB}
62	59.6^{D}	5.95^{BC}	4.92^{AB}	10.00^{B}	8.28^{B}

The breakage strength was highest at 30 weeks which results from the fact that small eggs are more resistant to breakage. If the eggs at 30 weeks are disregarded, it can be said that the highest breakage strength was displayed by the eggs laid at 38 weeks. Later, in spite of a slight parallel increase in egg weight and shell thickness, the breakage strength was found to decrease from 3.57 kg at 38 weeks to 3.28 kg at 46 weeks ($P<0.01$). In the subsequent weeks this value kept decreasing to 2.8 kg (Table 2).

The shell surface area was obviously increased when the egg weight reached its highest value of 71.3 cm^2 at 62 weeks (Table 2).

Shell density was highest at 46 weeks, estimated at 72.3 mg/cm^2 which is a statistically highly significant difference from shell density at 30 and 62 weeks (Table 2).

The lowest Ca content (1.84 g) in the shell was found at 30 and 62 weks. If, however, this quantity was enough in the early laying period to secure almost the maximum Ca level in 1 g dried shell, it was not enough in the last period and resulted in the minimum Ca level at 62 weeks (Table 3).

TABLE 2

Shell thickness, strenght surface area and density

Age wks	Shell thickness μm	Breakage strenght kg	Shell surface area cm^2	Shell density mg/cm^2
30	378.9^{A}	3.69^{A}	64.3^{A}	68.6^{A}
38	378.6^{A}	3.57^{A}	68.5^{B}	70.0^{ABa}
46	379.3^{A}	3.28^{B}	69.8^{C}	72.3^{Bb}
54	365.6^{B}	2.82^{C}	70.5^{CD}	71.0^{AB}
62	356.3^{C}	2.88^{C}	71.3^{D}	69.1^{A}

Means with the same superscripts within a column are not significantly different by Duncan's multiple range test.
Capital letters – at the level $P<0.01$, small letters – $P<0.05$

TABLE 3

Calcium and magnesium in shell

Age weeks	Total amount in shell Ca (g)	Mg (mg)	Level in mg/g Ca	Mg	Mg: Ca ratio ($\times 10^{-4}$)
30	1.84^{A}	17.31^{A}	416.6^{Ab}	3.93^{B}	9445^{A}
38	2.02^{B}	19.78^{C}	422.1^{Aa}	4.13^{A}	9802^{ABC}
46	1.89^{A}	18.91^{BC}	375.6^{C}	3.75^{BCa}	9990^{BCc}
54	1.92^{Ab}	19.61^{C}	382.9^{B}	3.93^{Bb}	10267^{Cc}
62	1.84^{Aa}	17.70^{AB}	373.3^{C}	3.59^{C}	9622^{AB}

Means with the same superscripts within a column are not significantly different by Duncan's multiple range test.
Capital letters – at the level $P < 0.01$, small letters at $P < 0.05$

The highest Ca level in 1 g of dried shell and its total content in the shell were at 38 weeks – 422 mg/g and 2.02 g, respectively.
The total amount of Mg in the shell and its level calculated per 1 g of shell were also the highest at 38 weeks.
The Mg:Ca ratio was the lowest at 30 and 62 weeks reaching its maximum value at 54 weeks (Table 3).

DISCUSSION

The calcified layer of the shell, which is also known as the spongy or crystalline layer, is the main part of the avian egg shell and is largely responsible for its mechanical strength. Chemically this layer consists of inorganic material (97% or more), remainder is constituted by macromolecules, called the organic matrix (Burley and Vadehra, 1989). Shell strength is considered a very important trait and is frequently used as a synonym for shell quality. Structural strength is dependent on the shape, size, thickness, and distribution of shell over the egg. The numerous techniques and methods that have been developed to measure shell strenght can be divided into two categories, direct and indirect methods. Resistance to impact and quasi-static compression fracture force are two practical direct methods used to measure shell strength. Specific gravity and nondestructive deformation are examples of indirect methods commonly used to predict shell strength (Hamilton, 1982). The others are shell weight and thickness, per cent shell and shell density (Belyavin, 1988).

Indirect methods are used to measure shell strength on the assumption that the values obtained are correlated with the direct values. However, correlation coefficients indicate that there is only a moderate relationship between the data from indirect and direct measurements (Hamilton, 1982).

Nordstrom and Ousterhout (1982) stated that small eggs had a much higher specific gravity ($P<0.001$) than large eggs with the same (0.380 mm) shell thickness. Brooks and Hale (1955) reported that only 58% of the variance in strength, measured by compression, could be explained by differences in shell thickness. Voise and Hamilton (1975) found by multiple regression analysis that thickness, egg size, egg shape, or nondestructive deformation separately or in combination, accounted for less than 57% of the variation in shell strength measured directly by the quasi-static compression technique. Shell strength has been difficult to study quantitatively because, according to Burley and Vodehra (1989), a reliable test that will predict resistance to breakage has been difficult to find.

PERCENT OF SHELL AND BREAKAGE STRENGTH

In the present experiment percent of shell was not significantly different between 38 and 54 weeks, while the difference in shell strength was at that time very large (3.57 and 2.82 kg) and statistically highly significant ($P<0.01$).

SHELL THICKNESS AND BREAKAGE STRENGTH

Shell thickness did not correspond with shell breakage. At 38 and 46 weeks shell thickness was maintained at a similar level, whereas, during this time breakage strength underwent a highly significant decline, from 3.57 to 3.28 kg.

SHELL DENSITY AND BREAKAGE STRENGTH

Low values for shell density occurred both at 30 weeks, when eggs were most resistant to breakage and at 62 weeks when breakage strength was the least. The highest values for shell density were not related with the highest breakage strength. The fact that there was no evident relationship between these two parameters seems of interest. Hamilton (1978) maintains that shell weight per unit of surface area is a useful indication of shell strength.

Ca LEVEL

In respect to shell composition, it should be mentioned that although calcium accounts for only 38% of the shell, its role is significant since in the form of $CaCO_3$ it constitutes, according to various authors, from 94 to 98% of shell weight (Niewiarowicz, 1970).

These differences seem to also result from the period of laying during which eggs were tested. From the results obtained in this study it follows that the level of Ca per 1 g of shell decreases considerably in the later period of laying. However, Mazanowska et al. (1986) reported very low values (315 mg/g) in fresh shells obtained at 2 and 6 months of laying and higher values (365 mg) closer to ours, at 11 months of laying. The Mg level, however, lower than reported in the present experiment, was found to decline with laying. The Mg:Ca ratio, based on their data, was also found to decrease.

Due to the fact that in the later part of the laying cycle the number of eggs decreased, explanations for age-associated decline in the Ca level per mg of shell include reduced calcium retention and changes in hormonal activity in the organism. Magnesium displays a similar pattern of changes during the laying cycle.

The NRC recommendations on Ca requirement in the diet for laying hens have increased from 2.27% Ca in 1944 to 3.80% Ca in 1984 or even to 4.55% for hens in the later period of the laying cycle (W.P.S.A. Recommendation, 1984) because of the lower Ca availability to older hens. However, if dietary calcium becomes too excessive, feed palatability, and thus feed consumption, is reduced (Roland et al. 1985). Moreover, in the experiment of Holder and Huntley (1978) there were no differences in egg shell thickness and Ca percentage in shells between eggs laid by hens given 2.5 or 3.5% Ca in diets. In our country, because of high feed consumption per hen and not very high laying performance, a level of 3.5% in the diet may be considered sufficient even during the later period of the laying cycle.

Mg LEVEL

In addition to calcium which constitutes the main cation in the egg shell, it also contains magnesium. However, it is not clear whether magnesium is associated with the crystals of the calcified layer or with protein (Burley and Vadehra, 1989).

According to Brooks and Hale (1955) magnesium ions increase the strength and hardness of the shell and Mg:Ca ratio is positively correlated with breakage strength.

In an earlier experiment by Kamińska (1990), Ca and Mg levels per gram of shell as well as the Mg:Ca ratio declined by a statistically highly significant degree between 45 and 53 weeks of hen's age as the shell strength decreased. The results obtained in the present experiment do not confirm this directly, although, a visible and statistically highly singnificant ($P < 0.01$) decrease in the Mg:Ca ratio occurred between 54 and 62 weeks, when the quality of the shell, estimated by the studied parameters, obviously declined. The highest values for the Mg:Ca ratio coincided with the highest values for shell density.

Britton (1977) stated that the Mg:Ca ratio decreased as shell deformation increased in eggs of young hens, but there was no such pattern in eggs of older hens. Stafford and Edwards (1973) reported that the magnesium content of the shell per se has little or no effect on the shell strength. Roberson and Francis (1966) found no beneficial effect on shell thickness when magnesium sulfate was added to the diet. Atteh and Leeson (1983) reported that dietary magnesium salts decreased the strength of the shell unless accompanied by extra calcium.

Balch and Tyler (1964), Simons (1971), Britton (1977) indicate that the shell membranes reinforce the crystalline part of the shell. Also Örberg (1990) has found that the bound between outer shell membrane and the shell proper contributes significantly to shell strength.

Egg shell quality depends on a balanced shell architecture in which different shell components contribute towards forming an egg that is resistant to breakage (Parsons, 1982).

Further research is required to develop a model that will explain shell strength on the basis of structural and chemical properties of the shell and its membranes.

CONCLUSIONS

The fact that shell weight does not keep pace with that of the egg and consequently shell thickness decrease, is not the only cause of its reduced resistance to breakage.

Breakage strength was not strictly related to shell density, thickness and percent shell.

During the laying period not only the total amounts of Ca and Mg in shells were undergoing changes but also the chemical composition of shells; the levels of Ca and Mg per gram of shell decreased. Their highest levels were found at 38 weeks on hen's age and the lowest at 62 weeks. These traits proved to be strictly related to egg shell breakage strength.

REFERENCES

Atteh J.O., Leeson S., 1983. Influence of increasing dietary calcium and magnesium levels on performance, mineral metabolism, and egg mineral content of laying hens. Poultry Sci., 62, 1261–1268

Balch D.A., Tyler C., 1964. Variation in some shell membrane characteristics over different parts of the same shell. Br. Poultry Sci., 5, 201–215

Belyavin C.G., 1988. Egg quality as influenced by production systems. World's Poultry Sci. J., 44, 64–67

Britton W.M., 1977. Shell membranes of eggs differing in shell quality from young and old hens. Poultry Sci., 56, 647–653.

Brooks J., Hale H.P., 1955. Strength of the shell of the hen's egg. Nature, 175, 848–849.

Burley R.W., Vadehra D.V., 1989. The egg shell and shell membranes: properties and synthesis. In: The Avian Egg Chemistry and Biology, Wiley, N. York

Hamilton R.M.G., 1978. Observation on the changes in physical characteristics that influence egg shell quality in ten strains of White Leghorns. Poultry Sci., 57, 1192–1197

Hamilton R.M.G., 1982. Methods and factors that affect the measurements of egg shell quality. Poultry Sci, 61, 2022–2039

Holder D.P., Huntley D.M., 1978. Influence of added manganese, magnesium, zinc and calcium level on egg shell quality. Poultry Sci., 57, 1629–1634

Hughes R.J., 1984. Estimation of shell surface area from measurements of length, breadth, and weight of hen eggs. Poultry Sci. 63, 2471–2474

Kamińska B.Z., 1990. Changes in amounts of yolk, albumen and shell, Ca and Mg in the shell and breakage strength during the laying cycle in hens. Proc. Polish Animal Science Association. Sept. 20–22 Szczecin

Lewis P.D., Perry G.C, 1987. Interaction of age, interrupted lighting and genotype on shell weight and density. Br. Poultry Sci., 28, 772, Abstr.

Mazanowska A., Korniewicz A., Kaczmarek K., Gwara T., Kozik E., 1986. Wpływ propionianu wapnia na nieśność kur i jakość jaj. Rocz. Nauk. Zoot., Monografie i Rozprawy, 24, 239–251

Nutrient Requirement for Poultry. Wolrld's Poultry Sci. J. 1984, 183–187

Niewiarowicz A. (Editor). 1970. Technologia jaj. Wyd. Naukowo-Techniczne. Warszawa pp. 13–39

Nordstrom J.O, Ousterhout L.E., 1982. Estimation of shell weight and shell thickness from egg specific gravity and egg weight. Poultry Sci., 61, 1991–1995

Oosterwoud A., 1987. Effect of egg handling on egg quality. In: Wells and Belyavin (Editors) Egg Quality – Current Problems and Recent Advances. Butterworth, pp.87–102

Örberg J., 1990. Relationship between the shell membrane – shell bond and shell deformation in hen's eggs. Br. Poultry Sci., 31, 249–254

Parsons, A.H., 1982. Structure of the egg shell. Poultry Sci., 61, 2013–2021

Roberson R.H., Francis D.W., 1966. Egg quality factors as affected by ascorbic acid, calcium lactate and magnesium sulfate additions to the rations. Poultry Sci., 45, 1119–1125

Roland D.A., Farmer M., Marple D., 1985. Calcium and its relationship to excess feed consumption, body weight, egg size, fat deposition, shell quality, and fatty liver hamorrhagic syndrome. Poultry Sci., 64, 2341–2350

Simons P.C.M., 1971. Ultrastructure of the hen egg-shell and its physiological intepretation. Thesis. Wageningen, The Netherlands

Skraba B., Kamińska B.Z., 1991. Changes in egg weight and egg-shell quality during the first laying cycle in hens. Proc. Inter. Symposium of Young Poultry Scientists. Sept. 4–6. Wrocław, Poland

Stafford J.E.H., Edwards N.A., 1973. Magnesium metabolism in the laying fowl. Br. Poultry Sci., 14, 137–148

Voisey P.W., Hamilton R.M.G., 1975. Behaviour of egg shell under compression in relation to deformation measurements. Br. Poultry Sci., 16, 461–470

Washington Bureau, 1991. Shell eggs broken in May up 8%. Feedstuff 63, No 27, 4

W.P.S.A. Recommendations, In: World's Poultry Sci. J., 1984, 40, 183–187

STRESZCZENIE

Zmiany jakości skorupy jaj w pierwszym roku nieśności kur

Sto cztery kury stada rodzicielskiego Astra S trzymano w pojedynczych klatkach. Od każdej kury brano do analiz po dwa jaja w 30, 38, 46, 54, i 62 tygodniu życia kur. Ogółem zbadano 845 jaj. Powierzchnię jaj określano wg wzoru: pow. jaja = masa $^{0.667} \times 4.67$, a gęstość skorup jako stosunek masy suchej skorupy bez błon do powierzchni skorupy. Zawartość Ca i Mg w suchych skorupach bez błon określono metodą spektrofotometrii absorpcji atomowej.

Masa jaj wzrastała przez cały okres nieśności, podczas gdy masa skorup tylko do 46 tygodnia. Po 46 tygodniach grubość skorup obniżała się statystycznie wysoce istotnie ($P<0.01$). Największą wytrzymałość jaj na zgniatanie stwierdzono w 38 tygodniu, natomiast największą gęstość skorup w 46 i 54 tygodniu. Zawartość Ca i Mg, tak w 1 g skorupy jak i w całej skorupie, była największa w 38 tygodniu. Stosunek Mg:Ca osiągnął najwyższą wartość w 54 tygodniu życia kur.

W okresie nieśności ulegała zmianom nie tylko całkowita ilość Ca i Mg w skorupie, lecz zmieniał się również skład chemiczny skorup. Te cechy okazały się być powiązane ściśle z wytrzymałością jaj na zgniatanie.