Reprint

ZOOTECNICA International

January 1990

Eggshell Strength: The Causes of Egg Breakage

Provimi Technical Service - Rotterdam, The Netherlands

Introduction

Demand for eggs of high quality is continuosly increasing. The new hybrids of breeds, strains and inbred lines made possible a higher production of eggs with a strong shell quality to cover that demand. Certain virus diseases such as infectious bronchitis and Newcastle result in a marked deterioration in shell structure, but with a good vaccination and medical care, problems will be solved.

Broken and cracked egg shells are responsible for major economic losses to egg producers. About 68% of the eggs annually produced are broken or cracked between the hen and the consumer's carton. These losses are estimated to cost U.S. producers $60 million annually. Reduction in shell breakage is a practical means for egg producers to increase their economic returns. In some cases, breakage may be reduced 1% by only cleaning and oiling the equipment that handles eggs between the hen and the consumer package.

It can be concluded that the majority of the shell breakage is due to interrelationships between eggshell quality and the many biological, environmental, managerial and nutritional factors. The purpose of this presentation is to find the evidence from the literature to solve the problem of eggshell quality and shell breakage and to help the managers to avoid these great losses of egg breakage in practice.

Factors affecting eggshell formation

Calcium

Hens receiving 3.5-4% calcium in all mash laying rations have been shown to retain only about 50% of the ingested calcium. A hen taking in 3.6 g of calcium per day retains about 1.8 g, per 1,800 mg, of calcium during the approximately 18 hours that feed is accessible. Thus, the hen retains about 100 mg calcium per hour. This is supported by studies showing that calcium absorption is in excess of 100 mg per hour when the egg is in the uterus but is much lower when no eggshell is being deposited.

Since a normal large egg contains about 2.0-2.2. g of calcium, the hen receiving her total calcium from an all mash ration must withdraw approximately 0.2-0.4 g of calcium from the bones during the night when the egg is still being calcified but no calcium is available from the feed.

If large particles of calcium carbonate in the form of oyster shell are substituted for a portion of the pulverized calcium carbonate in the all-mash ration, egg shell quality may be improved by supplying the hen with dietary calcium 24 hours per day.

Absorbing calcium at the rate of 100 mg per hour for 24 hours, the hen should then be able to retain 2.4 g of calcium, slightly more than the 2.0-2.2 g needed to make a good shell.

Sources of calcium

With exception of dried green meals, feedstuffs of plant origin are low in calcium. Thus fish meal, meat and bone scraps, bone meal, calcium phosphate supplements, limestone and oyster shells are the major feedstuffs supplying the calcium needs of layers. It was reported that crushed coral can serve as a satisfactory calcium source for laying hens.

Oyster shell

Experiments with oyster shell: Pulverized limestone and oyster shell or calcite grit as sources of the supplemental calcium were tested in various combinations. High producing hens were used in all experiments. The total dietary calcium was maintained at 3.5%. When oyster shell contributed 50-66% of the calcium supplement, the breaking strength was significantly better in eggs laid by hens fed oyster shell, as compared to those receiving only pulverized limestone.

TABLE 1. Calcium and phosphorus content of some minerals

Mineral source	Calcium (%)	Phosphorous (%)
Bone meal steamed	24	12
Calcium carbonate	40	—
Limestone	33-38	—
Oyster shell	37-39	—
Calcium phosphates:		
monocalcium phosphate	16.9	24.6
dicalcium phosphate	23.3	18
tricalcium phosphate	38.8	20
dicalcium phosphate (feedgrade)	24-28	18-21
curaçao island phosphate	35	15
defluorinated rock phosphate	33	18
soft (collaidal) phosphate	15-18	9
sodium phosphate monobasic	—	21.8

TABLE 2. Absolute dietary levels of calcium needed per day at different rates of production

Production %	Dietary calcium young pullets (22-40 weeks of age) *grams*	Needed per day mature hens (after 40 weeks of age) *grams*
100	3.3	3.7
90	3.0	3.3
80	2.7	3.0
70	2.3	2.6

Particles of calcium carbonate must be sufficiently large and hard to allow fragments to remain in the gizzard throughout the night. They must be sufficiently hard and of large enough surface to allow the gastric acidity to dissolve them at a rate that will release approximately 75 mg of calcium ion per hour to the blood stream.

It has been shown also that oyster shell, at a level providing a total dietary calcium of 3%, was somewhat better than either calcite grit or granulated egg shells as a source of supplemental calcium. However, both calcite grit and granulated eggshell produced significantly stronger shells than did pulverized limestone alone.

Optimum dietary level of oyster shell: High producing hens may hold the egg in the uterus for a much shorter time than do strains laying at lower rates. Oyster shell is needed much more in diets for these hens than for those which retain the egg in the shell gland over a longer period of time.

Since the response of various flocks of hens to dietary oyster shell varies, and their needs throughout the year also vary, it is difficult to arrive at a recommended level of oyster shell in the laying ration.

Calcium requirement for laying hens

High producing laying hens need enough calcium to produce the strong eggshells needed for current marketing conditions. The daily calcium requirements of hens at varying rates of egg production are shown in Table 2.

Although the egg at onset of lay weighs only about 45 g and this contains only approximately 1.5 g calcium, egg size at approximately 40 weeks of age is expected to reach approximately 56 g, whereupon the egg contains about 2 g of calcium. If one assumes that the young hen during this period is 60% efficient in utilization of calcium for eggshell formation, the hen would require 3.3 g of calcium per day for 100% egg production.

Assuming that the hen is capable of efficiently storing calcium in the bones on the days that she does not lay an egg, and that this calcium is used for subsequent egg production, the calcium requirement may be reduced, proportionately, as the rate of egg production decreases, as compared with the calcium needed laying one egg each day.

However, in commercial flocks of hens under present-day intensive egg production, it is anticipated that the average production of a flock during the first 40 weeks of age will be approximately 81% and that peak production may be as high as 95%. Under these conditions, many of the hens are laying at a rate of 100% production throughout much of the beginning of the laying period.

It is necessary, therefore, to provide all of the hens with a dietary level of calcium which is adequate for 100% production. A level of 3.3% calcium is needed as the calcium requirement of laying hens till about 40 weeks of age. After 40 weeks of age, egg size has increased such that most of the eggs contain about 2.2 g of calcium. Since many of the hens still are laying at a rate of almost 100% production and it is desirable to keep these hens laying at this rate as long as possible, the calcium level recommended for hens after 40 weeks of age is 3.7%.

Time of calcium intake

Time of calcium intake is important for shell formation. The most important time for the hen to receive calcium was during the afternoon. It was concluded that free-choice feeding large particles of calcium carbonate ($CaCo_3$) to layers in the afternoon, would seem to be only partially effective in supplying additional calcium at night for shell calcification. The mechanism which explains the beneficial effect of evening feeding on shell quality is as follows: The route calcium takes to the eggshell for morning fed birds is via the small intestine to blood to bone to shell gland and finally to shell. Hens fed dietary calcium in the afternoon at the beginning of shell calcification could deposit the calcium directly on the egg via the blood and bypass the bone. If this proposed mechanism is correct, more skeletal calcium should be in an egg shell from hens fed in the morning than from hens fed in the afternoon.

Effect of hot weather on shell quality

During hot weather, respiration rate of the hen increases from as little as 29 cycles per minute (in cool weather) to several hundred cycles per minute (in very hot weather). This hyperventilation decreases blood carbon dioxide to such an extent that a temperature increase from 13°C to 34°C has been shown to reduce shell thickness by approximately 12%. It was reported that an improvement in shell quality was obtained with increased atmospheric carbon dioxide levels.

An increase in atmospheric carbon dioxide over long periods of time produces an acidosis that is later compensated by reabsorption of bicarbonate from the kidney, thus increasing bicarbonate in the blood. By increasing the level of carbon dioxide in poultry houses, eggshell quality was increased and egg production also was improved.

Addition of sodium bicarbonate

Several investigations have attempted to increase the bicarbonate content of the blood by feeding sodium bicarbonate to the laying hen. As long as dietary chloride is high, chloride ions will be used as the main anion in the blood, and bicarbonate will increase very little in the presence of this high level of chloride. A reduction of dietary chloride to the minimum requirement, therefore, may improve shell quality by increasing bicarbonate reabsorption by the kidneys and thus a higher bicarbonate level of the blood. It was reported that a level of 0.2% sodium chloride will provide adequate chloride for egg production.

Addition of ascorbic acid

Addition of ascorbic acid (vitamin C) to the diet of laying hens has been reported to improve egg production and eggshell quality, especially in hot weather. Its possible beneficial effects have been studied in numerous laboratories throughout the world. It was reported that the level of ascorbic acid synthesized in the kidneys of laying hens satisfied physiological needs at optimum environmental temperatures, but that blood ascorbic acid decreased as environmental temperature increased from 21°C to 31°C. The decrease in blood ascorbic acid was postulated to be due to exhaustion of endogenous stores (adrenal ascorbic acid etc.) and also reduce kidney synthesis of vitamin C.

Addition of ascorbic acid to the diet (44 mg/kg) for layers prevented an increase in body temperature as the environmental temperature increased. Eggshell thickness decreased when body temperatures of the hens moved above normal, and this decrease was prevented only when the ascorbic acid prevented an increase in body temperature.

It was also reported that in a hot environment (30°C and 70-75% relative humidity) a supplement of 50 mg ascorbic acid (vitamin C) per kilogram of ration tended to improve shell quality as judged by deformation, breaking strength, shell thickness and percentage and amount of shell deposited per egg. It was concluded that the low shell quality was affected by low thyroxin secretion in the hot environment, which has been improved through the mediated effect on the thyroid gland by using vitamin C in the diet of layers.

Sources of eggshell breakage in the field. The procedures and equipment used for egg processing by various commercial producers and processors are similar, but there is considerable variation in the quality of their installation, repair, maintenance and operation. Generally, the procedures that have been developed to process eggs through commercial mechanized or semi-mechanized collection and grading systems from the 'cloaca to the consumer' use the same physical and engineering principles of operation.
The basic procedure can be divided into several stages to follow the extent of breakage of the eggs at the various stages between the hen and when they are put into the consumer's egg carton, including damage caused by the hen. For the purpose of discussion, these stages are (1) point of lay, including the rollout of eggs to an egg tray or collection belt, (2) transfer of eggs from laying cages to collection point, (3) washing and packing and (4) transportation. At each of these stages there are a number of factors that contribute to eggshell breakage.

Point-of-lay. A high incidence of breakage — about 3.5% of the eggs laid — occur at this stage. A number of variables have been identified as contributing to shell damage at this point. They include (a) the age of the hens (b) the stance of the hen at the time of oviposition, (c) the design of the cage system, (d) the design of the cage floor and the type of the material used, (e) the number of hens housed per cage and (f) the number of eggs in the egg tray or on the gathering belt.
Some of these variables are biological (a and b) and outside the control of the producer, whereas the producer has some control over the other mechanical factors (c to f). It was found that the breakage at the point-of-lay was 4.57% in the flat deck and 2.83% in a stair-step system. It was also noticed that 13.2% of egg cracked when the slope of the cage floor was 9.5 degrees, compared to 5.6% for slopes of 11.5 or 13.5 degrees. (The floor was 25 mm hexagonal mesh made from 1.6 mm decimeter wire supported by a wooden frame).
The extent of breaking during roll-out is closely related to the quality of maintenance of the cages, egg trays and collection belts, but trays, protruding wires or clip and improperly aligned collection belts also break eggs.

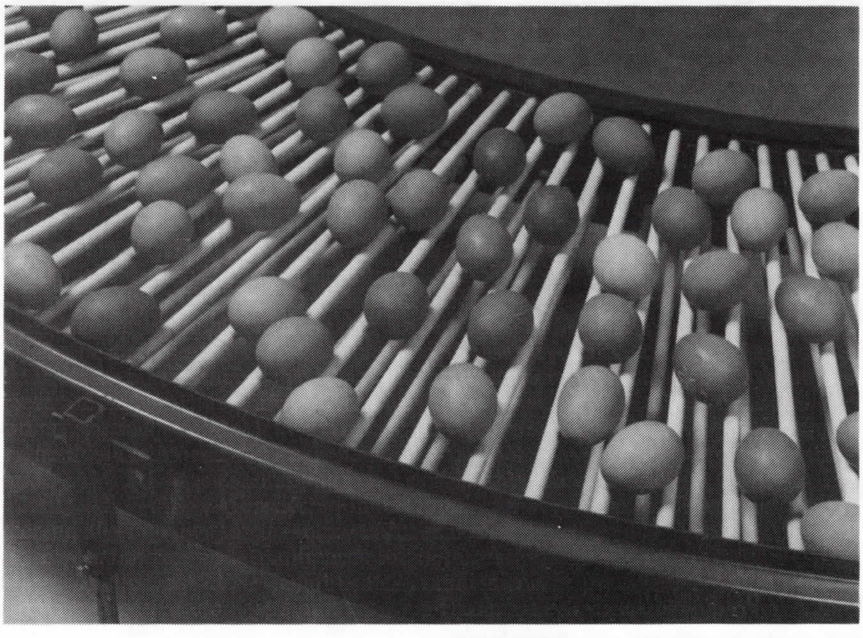
Transfer of eggs to collection point. Normally, breakage during this stage is low, although it can be higher than breakage at the point-of-lay. Again the maintenance of mechanical collection equipment is a major factor. Other factors include coordination of gathering intervals to avoid crowding of eggs on belts, relative speed (rate of travel) of belts, use of watertight and insulated tunnels in cold climates for main cross belts between buildings and the number of right angle turns and dimensions of the turn area. (It may be undesirable, however, to use insulated tunnels, because the shell strength increases as the temperature of the eggs decreases). These are some of the many factors that must be considered at this stage. For example, commercial operators consider that about 0.5% breakage is introduced for each 90% turn made by the eggs.
In the case of hand gathering operations, the quality of the 'hands' of the person, the additional duties this person is required to perform during egg gathering, the type of egg flat onto which the eggs are collected and the smoothness of the floor in the laying house, as well as between the laying house and the shipping area, affect the incidence of breakage.

Washing and packing. It was reported that an average of 3.6% of eggs received at the processing plant were broken and an additional 3.7% were broken in the processing plant. A little more than half of the breakage at the processing plan (2.0%) occurred during packaging and packing. The correct functioning of equipment is a major factor that determines the amount of breakage in these operations. Some other factors that contribute to breakage in these operations include inadequate amount and quality of labor, old filler-flats and cases and material handling practises and stresses during washing, which may be thermal (i.e., wash water temperature) or mechanical (i.e., whether the water is delivered by gravity flow or under washing brushes). Concerning the material used for cartons, there was a strong indication that, based on molded pulp and polystyrene cartons, carton design was more important than material in determining the relative protective ability.
In the situations where eggs were washed and graded at a central plant, packing of the eggs for transportation from the farm to central plant is critical, and the same factors as previously discussed are equally as important.

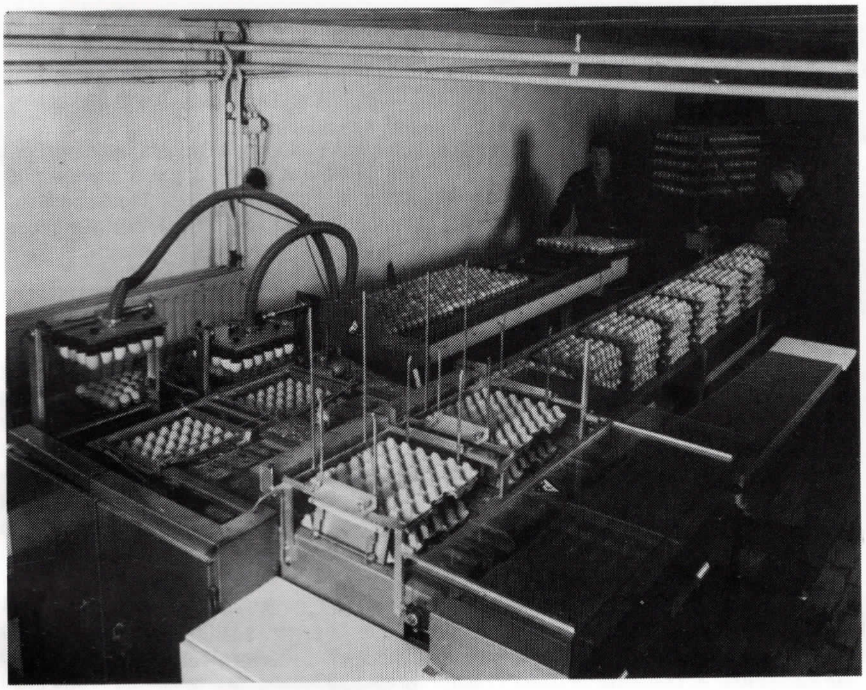
Transportation. Transportation accounts for about 1% breakage of all eggs produced. This damage is influenced by such factors as (a) means by which the cases or carts off eggs are placed in the vehicle and secured, (b) amount and quality of the labor loading the vehicle, (c) manner in which the vehicle is driven, (d) nature of roads over which the vehicle travels and (e) the type of suspension on the vehicle.

Biological, environmental and managerial factors related to eggshell breakage
There are several biological, environmental and managerial factors that influence shell breakage at various or all stages in the movement of eggs from the producer to the consumer.

Age of the laying flock. Age of the laying flock is an important factor that influences shell quality. It was reported to be 2.7% breakage during the first month and 13.5% in the 15th month of lay. Age had no apparent effect on the proportion of the breakage that occured between the hen and processing plant and the in-plant breakage.
Age also affects egg size, which may partially explain the decrease in shell



Proper transportation of eggs from production facilities to packing centers is essential for minimizing egg breakage (photo courtesy of Big Dutchman)



Modern, reliable equipment and qualified personnel are important in traying and packaging operations (photo courtesy of Petersime)

quality during the first laying period. It was observed that egg size increases more rapidly than shell weight and that consequently there is a concomitant decrease in shell thickness and percent shell. These observations indicate that the eggshell quality of eggs from older hens may be improved by controlling egg size.

Time of day when eggs are laid. Time of day when eggs are laid is another biological factor that affects shell quality and breakage. Eggs laid in the afternoon have higher specific gravity. This factor is related to the formation period in hours because an egg that stays longer in the uterus puts down a stronger shell.

Environment. This point has been discussed before, but for its importance it will be mentioned as one of the biological or physiological factors.

Temperature. Temperature affects egg breakage in several ways. It is a fact that elevated environmental temperatures are associated with a decrease in shell quality. The relationship between environmental temperature and shell thickness is curvilinear with a temperature ranging from 26.5 to 35°C. It was suggested that the reduction in shell thickness produced by heat stress is apparently due to respiratory alkalosis, which causes loss of excessive amounts of carbon dioxide from the blood.
The temperature of the egg during preprocessing also affects eggshell breakage.
Allowing eggs to cool before handling or transporting from the laying house reduces damage because shell breaking strength increases with decreasing shell temperature.
In subtropical and tropical areas, it is greatly advisable to cool the houses to increase production, egg weight and shell quality.

Humidity. This aggravates the temperature effects on layers. Lowering the relative humidity from 70 to 25% at 29.5°C improved shell quality significantly. In practice, we are lowering the temperature and increasing the humidity when we use the evaporative coolers.

Evaporative coolers. The purpose of evaporative cooling is simultaneous cooling and humidifying the outside air, which, because of its high temperature and low humidity, is not a suitable environment for poultry. Hot air can hold more moisture than cool air. The process of evaporation of water requires energy. The principle of evaporative cooling is based on mixing hot and dry air with very small atomized droplets of water, which are evaporated with the heat in the air. The heat required for this process is derived from the warm air resulting in a decrease of air temperature and an increase in humidity. Warm and dry air is extremely suitable for this process.

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