Examining avian eggshell, bone mineralization in extended laying cycles

Why are trace minerals important?

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Decades of intensive genetic selection in commercial layers has resulted in earlier maturation, while sustaining high lay performance in extended production cycles until 100 weeks of age, in order to make egg production more sustainable. However, intensive egg production challenges hen health and, particularly, skeletal integrity. Eggshell formation requires mobilizing large amounts of calcium, coming in part from the diet and from bone, which could induce skeletal problems such as osteoporosis and bone fractures. Also, eggs with poorer quality eggshell with cracks or defects are more frequently laid by older hens. These eggs need to be downgraded, causing important economic losses.

Poor eggshell quality is a major concern for food safety, as eggs with a damaged eggshell are more easily contaminated with bacteria, e.g. *Salmonella*. What can we do to deal with these problems?

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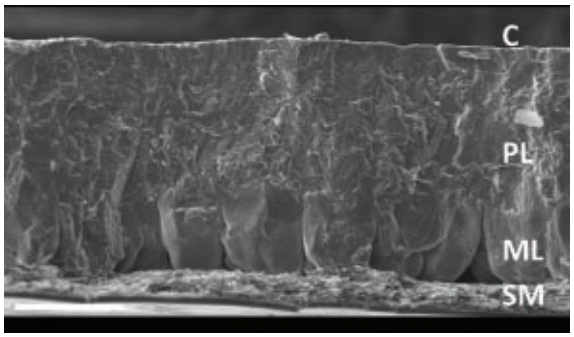
Adequate nutrition and management can help achieve the genetic potential of modern layers while maintaining eggshell quality and skeletal integrity, as well as the overall hen health during the extended production cycles.

Avian eggshell mineralization

Eggshell formation and mineralization is a highly calcium-demanding process. Hens need to mobilize more than 2 grams of calcium daily, equivalent to 10% of their total body calcium. In general, calcium comes in part from the diet and in part from the skeleton; the relative contribution varies depending on the availability of dietary calcium. To obtain an adequate supply of calcium, a stimulated production of vitamin D leads to an increase in calcium absorption by intestinal and uterine tissues.

Eggshell mineralization starts about 5 hours post ovulation by the accumulation of amorphous calcium carbonate (ACC) particles on mamillary knobs forming massive mineral islands. Mamillary knobs are organic structures rich in proteoglycans forming on the eggshell membrane surface having a strong calcium binding capacity.

Later on, ACC mineral deposits progressively dissolve and give way to calcite single crystals. Calcite crystals radiating from the nucleation sites produces the mammillary cones or the lower part of the mineralized shell from which columnar mineral units or palisades emerge, which constitute the bulk of the eggshell mineral thickness.



Eggshell ultrastructure as seen by electronic microscopy showing the shell membranes (SM), mammillary layer (ML), palisade layer (PL) and the cuticle (C). *Source: Dr. A. Rodriguez-Navarro*

Finally, eggshell formation terminates with the deposition of the cuticle, a very thin organic layer coating the eggshell outer surface that prevent bacteria from entering the egg interior.

EGGSHELL QUALITY DEPENDS ON many factors including hen breed, age, nutrition and housing.

In any case, calcium carbonate mineral deposition is stimulated by a Zn-dependent enzyme (carbonic anhydrase). A second step is the regulation of crystal growth, which is stimulated by a Mn-dependent enzyme (glycosyl transferase).

Eggshell is also a source of Ca for embryo skeleton mineralization. The Ca metabolism is greatly stimulated during egg laying. This process needs a synchronization between bone turnover and eggshell formation.

About bone

Bone is a living organ that is under constant remodeling by bone forming (osteoblast) and bone resorbing (osteoclast) cells. Among its functions here is the calcium and phosphorus regulation for basic cell functions.

Specific for hens, they develop a new type of bone within the marrow cavities of their long bones (medullary bone) that is metabolically active and can be more easily resorbed to release calcium. The formation of

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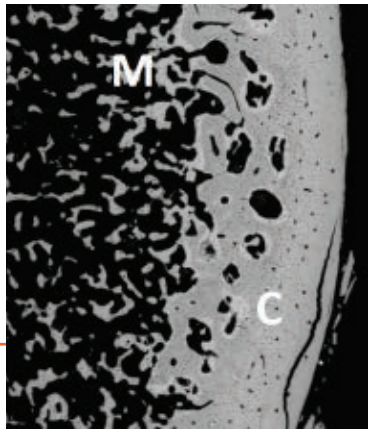
medullary bone starts about two weeks before laying the first egg when the hen reaches sexual maturity. Medullary bone serves as a calcium reservoir for eggshell calcification during the night when hens are not eating and the intestinal calcium supply is exhausted. The formation and resorption of medullary bone is synchronized with the egg daily cycle. Thus, bone and eggshell mineralization are interrelated.

Bone remodeling involves osteoclasts removing mineralized bone, succeeded by osteoblasts forming new bone matrix, which subsequently mineralizes. The remodeling cycle includes three stages:

- Resorption, where osteoclasts digest old bone tissue
- Reversal, marked by the appearance of mononuclear cells on the bone surface
- Formation, where osteoblasts deposit new bone until the resorbed bone is completely replaced

This process adapts bone architecture to varying mechanical demands and repairs micro damages in the bone matrix, preventing the buildup of damaged aged bone.



Cortical (C) and medullary (M) bone of a tibia from a laying hen with osteoporosis.

Source: Dr. A. Rodriguez-Navarro

Eggshell and bone quality

The eggshell quality can be affected by the hen strain (brown lines of birds are heavier and lay larger eggs with thicker/stronger eggshells), age (eggshell cuticle deposition decreases with hen age), nutrition (deficient supply of Ca, Fe, Cu, Zn, Mn and vitamin D can impair eggshell formation), housing and lighting programs.

Weak eggshells are characterized by:

- Thinner eggshells and smaller effective thickness
- Several structural defects (late fusion of mammillary cones, poor membrane attachment)
- Low mammillary density

There are many approaches (genetic selection, management) to improve eggshell quality and food safety of eggs.

Bone quality depends mainly on genetic factors (onset of puberty). However, the high calcium demand during lay seems to be associated to bone osteoporosis and other bone pathologies. The age of the hen can also impair bone quality and increases the risk of bone fractures.

Weak bones are characterized by lower density and low ability to regrow (remodel) themselves.

Bone quality can be improved by genetic selection, nutrition and management independently to egg production.

Conclusion

Eggshell and bone mineralization are regulated in a coordinated manner, influenced by various factors including mineral nutrition. An adequate supply of calcium, phosphorus, trace minerals and vitamin D is essential for these processes. For older hens, proper nutrition becomes even more crucial to prevent broken eggs and bone fractures. ■

References available upon request.

Editor's note: This is the fourth installment in a six-part series of articles. This article is based on Dr. Alejandro Rodriguez-Navarro's presentation, "Avian eggshell and bone mineralization in long laying cycles," made at the Animine Academy, held on September 2, 2023, in Lyon, France.

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