THE SCIENCE OF EGG QUALITY

"I think if required on pain of death to name the most perfect thing in the universe, I should risk my fate on the bird's egg"

—T.S. Higginson, 1863

EGG QUALITY

A good quality fresh egg has an elliptical shape with a clean, smooth and shiny shell surface. The eggshell is free of cracks and other defects. In white egg varieties, the shell color is uniformly pure white; while in brown egg varieties the shell appears uniformly dark brown. After breaking the egg and placing the contents on a flat surface, the albumen has a clear or slightly opaque, jelly-like stacked-up appearance and should be free of inclusions (meat and blood spots). An intact yolk is a uniform bright yellow to orange color and anchored in the center of the egg by the chalazae which are not excessively large. The egg contents are free of odor and microorganism contamination.

REPRODUCTIVE TRACT OF THE HEN

The reproductive tract in the hen is called the oviduct. Females of many species of animals have two functional oviducts; however, in birds only the left oviduct develops. The time for egg formation in the oviduct is approximately 24 to 28 hours, from ovulation to egg laying (oviposition).

Ovary

The developing ovum (yolk) grows and matures within follicles on the ovary. The follicle, when mature, ruptures and releases the ovum into the oviduct (ovulation). Ovulation usually occurs within minutes of the hen laying the previous egg. The yolk undergoes no further development after ovulation.

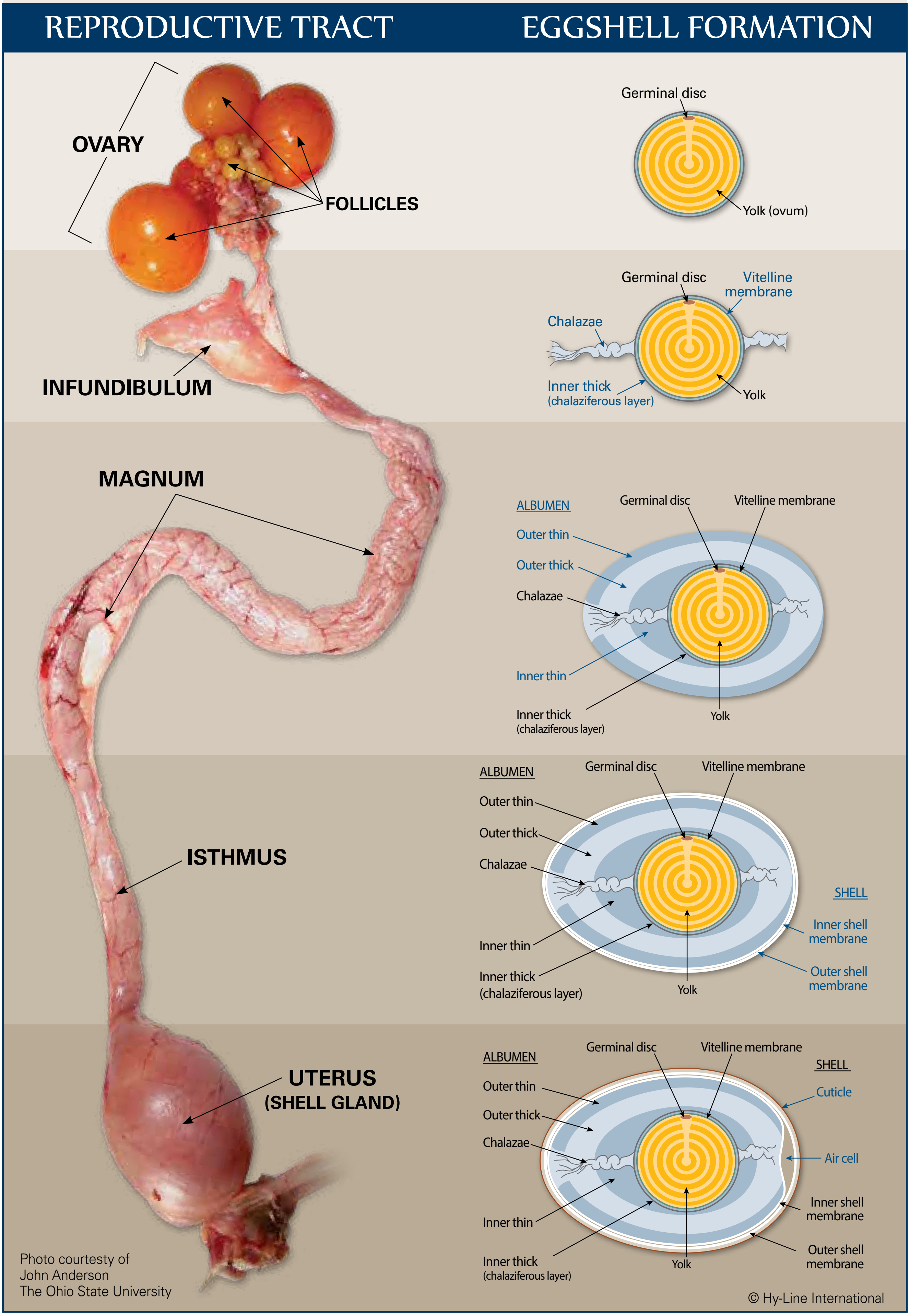
Yolk size is an important measure to egg processors because 70% of the egg solids are contained in the yolk. The color of the yolk is another important quality characteristic of eggs for consumers and commercial customers. Yolk color is completely determined by the types and amounts of pigments, either natural or synthetic, in the hen's feed and the ability of the hen to absorb and assimilate these pigments. Therefore yolk color is not an important trait for selection by genetic companies.

Infundibulum

The primary function of the funnel-shaped infundibulum is to capture the yolk at the moment of ovulation from the ovary. The first layer of thick albumen surrounding the yolk is secreted in the infundibulum. The precursors to the chalazae are also added in the infundibulum. The chalazae are twisted albumen strands at either pole of the egg and function to anchor the yolk in the center of the egg. The egg spends only 15 to 30 minutes in the infundibulum before passing into the magnum.

Magnum

The largest portion of the oviduct is the magnum, where the albumen or "egg white" is added around the yolk. The albumen portion of the egg surrounding the yolk is in four distinct layers made of thin, watery albumen (outer thin albumen layer and inner thin albumen layer) or thick, semi-solid albumen (chalaziferous albumen and inner thick albumen layers). The thick albumen makes up the greatest proportion of the albumen. Egg albumen constitutes roughly 60% of the whole egg and contains over 40 different proteins. The major albumen proteins are ovalbumin, ovotransferrin, ovomucoid and ovoglobulins. Ovomucin, a fibrous protein, is important for albumen quality, because it tightly holds the albumen into a gel, giving it form and substance.


REPRODUCTIVE TRACT
EGGSHELL FORMATION
OVARY
FOLLICLES
INFUNDIBULUM
MAGNUM
ISTHMUS
UTERUS
(SHELL GLAND)
Germinal disc
Yolk (ovum)
Germinal disc
Vitelline membrane
Chalazae
Inner thick (chalaziferous layer)
Yolk
ALBUMEN
Outer thin
Outer thick
Chalazae
Inner thin
Inner thick (chalaziferous layer)
Germinal disc
Vitelline membrane
Yolk
ALBUMEN
Outer thin
Outer thick
Chalazae
Inner thin
Inner thick (chalaziferous layer)
Germinal disc
Vitelline membrane
Yolk
SHELL
Inner shell membrane
Outer shell membrane
ALBUMEN
Outer thin
Outer thick
Chalazae
Inner thin
Inner thick (chalaziferous layer)
Germinal disc
Vitelline membrane
Yolk
SHELL
Cuticle
Air cell
Inner shell membrane
Outer shell membrane
Photo courtesy of
John Anderson
The Ohio State University
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A good quality, fresh egg is associated with albumen that is compact, "stacked up" with the gel-like appearance. Watery albumen is disliked by consumers and associated with an egg that is old. The amount of thick albumen is greatest when the egg is laid and then slowly begins breaking down into thin albumen by the action of the enzyme lysozyme. Factors affecting the rate that thick albumen is converted to thin albumen are the age of the egg and the temperature during egg storage. Also, thick albumen decreases with advancing age of the hen. Some diseases affecting the oviduct such as Infectious Bronchitis and Egg Drop Syndrome can decrease thick albumen, as can general stress. The amount of thick albumen can be increased through genetic selection and significant differences between commercial varieties exist.

Isthmus

This region of the oviduct is where the shell membranes (inner and outer) are added to the developing egg. In the isthmus, specialized structures called mammillary bodies are secreted onto shell membranes. These structures are important in the calcification of the eggshell.

Uterus

The uterus is also known as the shell gland and is the site of eggshell formation. As the egg leaves the isthmus, the shell membranes are slack and wrinkled. The shell membranes are made tight as the egg enters the uterus by a process called "plumping". Water is pumped through the egg membranes into the albumen. The albumen volume is doubled during the "plumping" process, giving the egg its final shape. Pulling the shell membrane tight and removing wrinkles is critical for proper shell architecture and optimizing the transfer of calcium during shell formation. "Plumping" of albumen is decreased with the hen's age and from some diseases such as Infectious Bronchitis and Egg Drop Syndrome.

The high blood flow within the uterus is essential to the transfer of large amounts of calcium to the egg. Typically, 2 to 3 grams of calcium are added during eggshell formation. Calcium and carbonate ions from the blood are transferred to uterine fluid that bathes the outer eggshell membrane. Calcium is transported to the egg at a rate of 300 milligrams per hour.

Vagina

The vagina plays no role in the development of the egg. The egg is held in the vagina until the hen has nested and is ready to lay the egg.

The Reproductive Tract

	Length	Egg Formation Time
Infundibulum	10 cm	15-30 minutes
Magnum	30 cm	2-3 hours
Isthmus	10 cm	1 hour
Uterus	8 cm	18–20 hours

LAYERS OF THE EGGSHELL

Shell Membrane

The shell membranes are added to the egg in the isthmus section of the oviduct. The calcified shell is formed on the egg membrane. Defects in the shell membrane or failure to "plump" the albumen will cause defective calcification, poor structure and shell weakness.

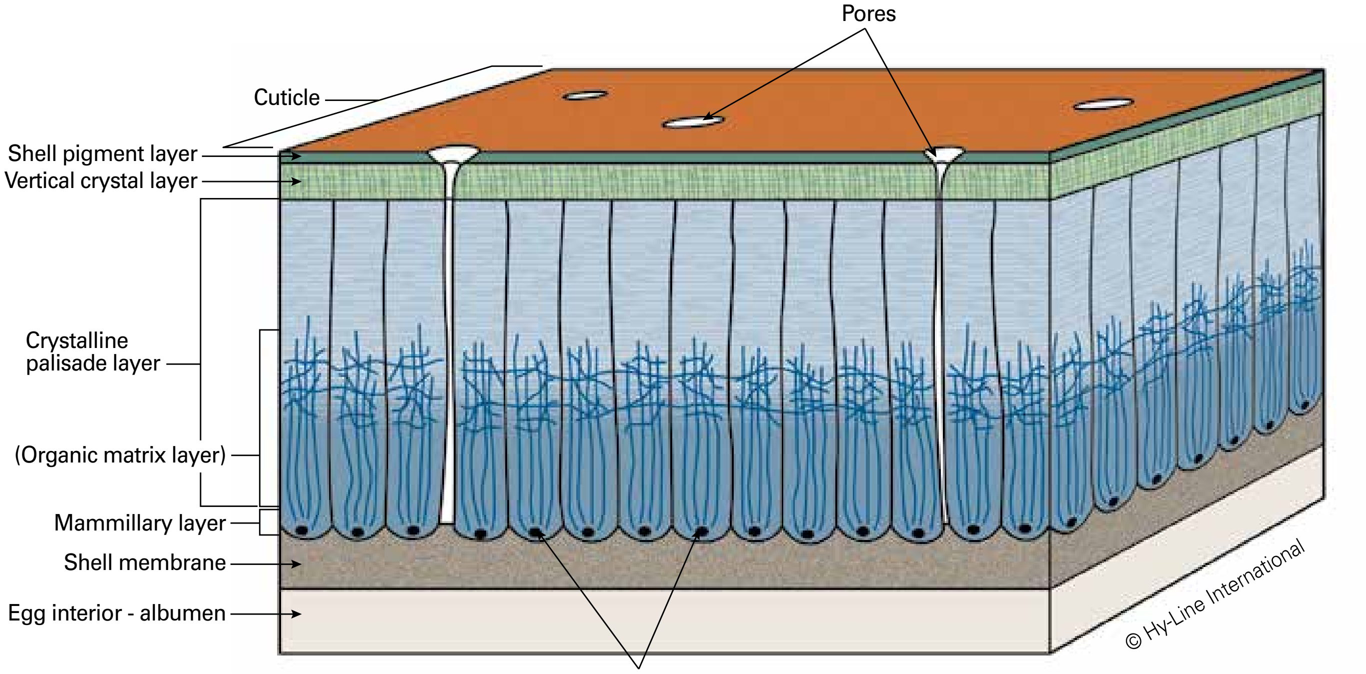
Mammillary Layer

Within the isthmus, mammillary bodies develop on the egg membrane. These bodies are firmly anchored into the outer shell membrane and are important in initiating the shell calcification process. Mammillary bodies should form a continuous sheet, covering the entire shell membrane. The distribution of mammillary bodies is under genetic control. Problems with this layer will result in poorly organized shell structure and weakness in shell strength.

Organic Matrix Layer

Within the uterus, shell calcification begins with the production of a matrix of protein fibers by the mammillary bodies. The organic matrix is found throughout the crystal layer of the shell and provides a latticework where the crystallization of calcium salts occurs during eggshell creation. The organic matrix gives the shell added strength by properly orienting the calcium crystals to form a palisade (columnar) architecture. The protein fibers of the organic matrix are generally oriented parallel to the shell membrane surface and gives the eggshell its elasticity and shock resistance. Problems with the formation of the organic matrix will negatively impact shell strength, even with adequate shell thickness. Shells with a poorly formed organic matrix layer will be more "brittle" and prone to breakage.

Structure of the Eggshell



Crystalline Palisade Layer

The crystalline layer is made of densely packed crystals of calcium in the form of palisades. These palisades of calcium crystals are oriented perpendicular to the shell surface for added strength. The palisades eventually become fused together into a proteo-ceramic as shell thickness increases. The majority of crystals are calcium carbonate (96%) with small amounts of magnesium carbonate and tricalcium phosphate crystals. Magnesium is important to add hardness to the shell structure. The crystalline layer makes up the greatest proportion of the shell thickness and provides mechanical strength. The amount of shell deposited on eggs is determined by the time spent in the uterus (shell gland) and the rate of calcium transfer via uterine fluid. Normally, a hen secretes a fairly constant amount of eggshell each day independent of the egg size. Shell thickness decreases with advancing age of the hen as the egg becomes larger; also the rate of this decline is affected by diet and genetics. Shell thickness is restored when the hen undergoes a molt. Heat stress and disease can adversely affect shell thickness.

Vertical Crystal Layer

The outermost layer of the eggshell is the surface vertical crystal layer. This is a thin layer of dense calcium crystals that are oriented perpendicular to the shell surface, providing hardness and smoothness to the shell surface.

Pigment Layer

Eggshell pigments are deposited into the shell at the end of the shell calcification process. The colors of brown and white eggshells are both results of the same pigments deposited at different rates within the cuticle and outer calcified layers of the shell. Eggshell colors in commercial layers range from pure white through "cream tinted" to "brown tinted" to brown. The wide variations in shell colors are due to combinations of light hues. The major shell pigments are protoporphyrin and biliverdin, which are produced during the metabolism of hemoglobin, the oxygen carrying molecule in red blood cells. These pigments are transported in the blood from the liver to the uterus. Shell pigments may also be produced from red blood cells within the uterus. Production of shell pigment is greatest in young hens and gradually diminishes with advancing age. Normally, an adult hen secretes a fairly constant amount of egg pigment independent of the egg size. Shell color in older hens can be restored with molting. Diseases affecting the reproductive tract can result in loss of shell pigmentation. Generalized stress and exposure to sunlight can also reduce shell color. Genetics exerts a big influence on shell color and selection for dark and uniform color in brown hens and pure white color in white eggs has resulted in superior varieties in this trait.

The presence of shell speckles (spots) is common in brown eggs. Speckles are areas where a higher concentration of pigment is deposited. From the evolutionary perspective, speckling is an adaptive trait; most wild bird species use it as camouflage to hide hatching eggs. In the evolution of the modern chicken, speckling had a selective advantage, so now we are working against nature to remove this trait. Speckling has been successfully reduced with genetic selection; however, this must be done carefully as the incidence is negatively correlated with overall shell color.

Cuticle

The outermost layer of the shell is the cuticle. This is a non-calcified proteinacious layer added to the shell just before it leaves the uterus. The cuticle is responsible for the smooth, glossy appearance of a freshly laid egg. The cuticle protects the egg from invasion with microorganisms. Washing eggs removes the cuticle. On the surface of the cuticle are pores (openings) that extend through the calcified layer to the egg membrane. These pores are responsible for the exchange of gases (oxygen into the egg and CO_2 out) and loss of water vapor from the egg interior. A typical hen's egg contains 6,500 pores, with the greatest concentration of pores at the blunt end of the shell over the air cell.

Blood and Meat Spots

Blood and meat spots are undesirable inclusions sometimes found in the egg. Blood and meat spots diminish the acceptability of the egg by consumers and bakeries. Blood spots are usually the result of hemorrhage within the ovarian follicle before or during ovulation. This blood is carried with the yolk into the oviduct and becomes a part of the egg contents. Blood spots appear as bright red streaks or blood clots either attached to the yolk or free in the albumen.

Meat spots are darker in color, granular and occur in the albumen. They may be caused when cellular debris from the oviduct is picked up by the egg before the shell membranes are secreted. Meat spots may be also blood spots where the hemorrhage occurred days before ovulation and the hemoglobin has degraded and darkened in color.

Blood and meat spots occur more frequently in brown egg varieties than white egg varieties. The incidence of blood and meat spots can be reduced through genetic selection. Hy-Line has developed a scoring system to rate meat and blood spots separately with each egg processed in the Egg Quality Laboratory being scored for these internal defects. That data is then included in the selection process and commercial varieties with very low incidence have been developed.

ENSURING GOOD EGG QUALITY

Disease Control

Proper disease diagnosis and good vaccination programs are important to minimize the infectious disease incidence in a flock. Infectious Bronchitis and Egg Drop Syndrome have already been mentioned as diseases that can have significant impact on shell quality. Other diseases that could affect shell appearance include Newcastle Disease and Avian Influenza. Stress from any disease can indirectly result in loss of egg quality.

Nutrition

Shell strength is determined by the calcium metabolism of the hen which is a dynamic flow of calcium from the feed and bone to the uterus. There is a demand of 2–2.5 grams of calcium per egg produced, almost regardless of egg size. This calcium requirement must be principally supplied by the feed, but the hen may also mobilize calcium from medullary bone reserves to form the eggshell. Medullary bone acts as a readily available reservoir of calcium if required during shell formation. The quantity of calcium contributed to the eggshell from these bone reserves will depend on the rate and quantity of calcium absorbed from the digestive contents during shell deposition. When adequate calcium is supplied by the diet, the bird will replenish and maintain the medullary bone calcium content during periods when no shell formation is occurring. If dietary calcium supply is inadequate, then calcium will be mobilized from cortical bone to meet the required levels for proper shell formation. Continued calcium deficiency will result in the appearance of soft bones and eventually a drop in production, or in acute deficiency, the bird will stop laying.

Unless a bird enters into molt and experiences a drop of estrogen levels, the skeletal bone is not replenished with calcium. Shell quality cannot be maintained for long without adequate levels of calcium, phosphorus and Vitamin D in the layer diet. Other micronutrients including Magnesium, Iron, Copper, Manganese, Zinc, Vitamin K and certain amino acids function in calcium transport and bone matrix turnover. Even some B vitamins (Folic acid, Niacin, B12) have been associated with positive effects on shell quality.

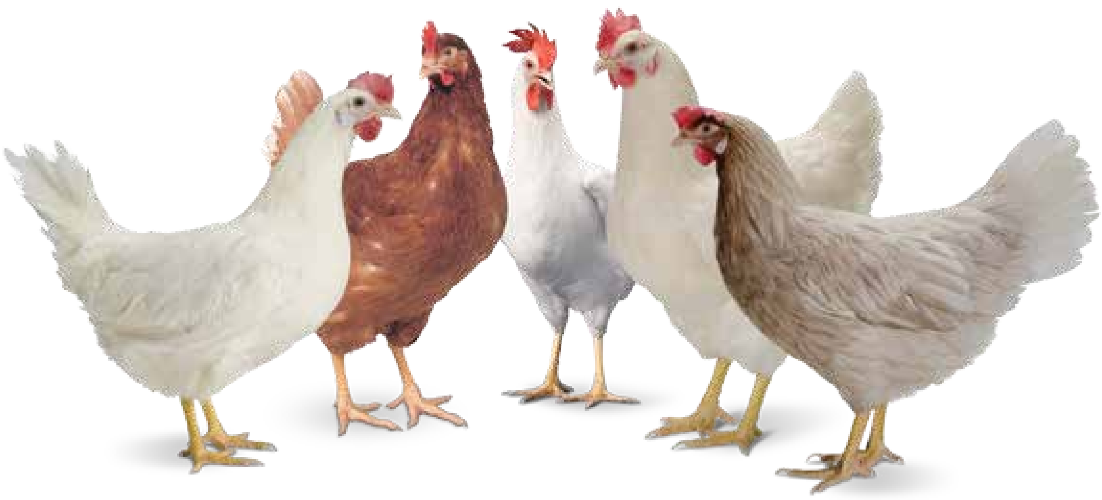
Dietary electrolyte balance is also an important consideration for shell quality as it can influence the mineralization of the shell. High levels of dietary chloride should generally be avoided. Replacing a proportion of the sodium from salt with sodium from sodium bicarbonate or sodium carbonate sources has been shown to have positive impact on shell quality.

Vitamin D is essential for the intestinal absorption of calcium and phosphorus. Phosphorus is present at a low level in the eggshell, but is important for replenishing the medullary bone. So there must be sufficient phosphorous available from the diet to assimilate the calcium into the bone matrix. The mobilization of calcium from bone is inefficient and should be minimized by supplying calcium mostly from dietary sources. Late afternoon feedings, midnight feedings and coarse limestone particle size extend calcium absorption from feed into the night time period. These measures preserve medullary bone and lower the demand for dietary phosphorus.

Recommended minimum daily intake levels for calcium and phosphorus are provided in the table below. The Hy-Line Performance Standard Manuals should be consulted for the specific levels of other micro and macro nutrients. The recommendations serve as a reference but the level of production should also be considered. Hens producing egg numbers in excess of the Hy-Line standards will have a greater calcium requirement for shell formation and therefore the dietary concentration should be adjusted accordingly. Additional consideration should be given to the particular source of calcium as limestone from different sources varies in solubility and therefore, availability to the bird.

Nutrition for Good Eggshell Quality

	Growing	Pre-lay	First Egg to Peak	Peak to 90%	89% to 85%	Less than 85%
Calcium	1.0%	2.5 – 2.75%	4.0 – 4.2 grams/day	4.25 grams/day	4.40 grams/day	4.50 grams/day
Phosphorus, available	0.48%	0.5%	0.5 grams	0.48 grams	0.46 grams	0.40 grams
Vitamin D, I.U per day	3,300,000 I.U / ton of feed					
PARTICLE SIZE RATIOS OF CALCIUM CARBONATE						
Fine – <1 mm	100%	50%	45%	40%	35%	30%
Coarse – 2-4 mm	0%	50%	55%	60%	65%	70%



HEAT STRESS AND SHELL QUALITY

The heat stressed flock often lays eggs with thinner, weaker shells because of acid/base disturbances in the blood as a result of panting (hyperventilation). As the hen pants to lose body heat there is excessive loss of CO_2 gas from the blood. Lower CO_2 causes blood pH to elevate or become more alkaline. The higher blood pH reduces the amount of ionized calcium and carbonate delivered to the uterus for eggshell formation. Increasing the amount of calcium in the feed does not correct this problem.

Reduced feed intake under heat stress conditions also contributes to thin eggshells. The dietary electrolyte balance can also play a role in shell quality, particularly during periods of heat stress. The concentration of chloride in the diet should be carefully balanced in relation to sodium and potassium and even reduced during hot periods. Some additional benefits may be expected with the use of bicarbonate sources.

MEASUREMENT OF SHELL AND EGG QUALITY

Shell Thickness

Many labs and companies use the measurement of shell thickness as the only indicator of shell quality. However, the eggshell is a proteo-ceramic and its functional properties are not necessarily directly related to its thickness. A more resilient shell is one that can absorb and tolerate more impact and other physical forces without cracking. Shell integrity is related to its structure and the pattern in which the calcium minerals are deposited (i.e. crystal size and organization) to form the different layers of the shell. From the breeding standpoint, selecting only for increased shell thickness is not sufficient.

Puncture Score

Puncture score is a test used to measure the plasticity of the shell. As the test doesn't damage the integrity of the shell, the Puncture Score can be measured at more than one location on the shell, allowing for better accuracy. Measuring Puncture Score requires special instrumentation and calibration and is not a widely used measurement of shell quality in the industry.

Breaking Strength

Breaking Strength measures the amount of force required to break the shell. It is a pure resistance measurement, and as it is destructive, only one measurement per egg is possible.

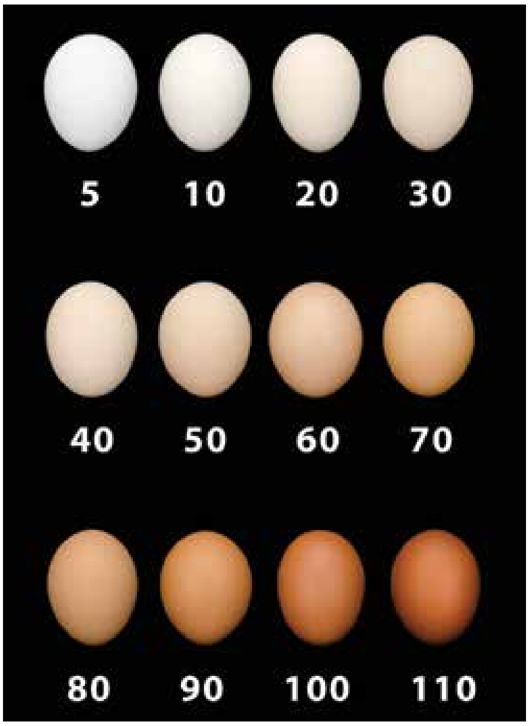
Acoustic Resonance

A large body of research proves the usefulness of acoustic resonance and its derivate measures, such as the "dynamic stiffness" or dynamic shell strength (Kdyn), in predicting shell quality. The Acoustic Egg Test device developed by the University of Leuven, Belgium provides accurate and repeatable values of acoustic frequency and Kdyn. In addition, the test classifies eggs as "cracked" vs. "normal" and also identifies micro-cracks, which are not visible with the naked human eye.

The use of dynamic stiffness to improve shell quality is important in selection of pure line layers. Hy-Line measures large numbers of eggs throughout the production period to ensure selection pressure continues on this important trait.

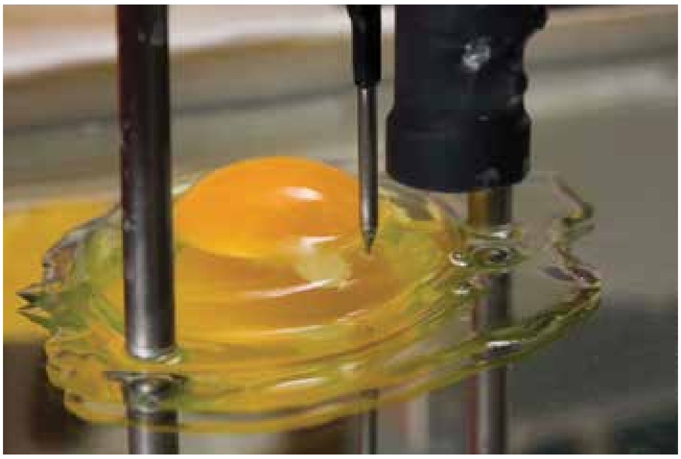
Shell Color

Shell color is an important trait to be studied due to different market preferences regarding egg color around the world. While there are a variety of options, Hy-Line uses an internal shell color index based on the three-parameter (L,a,b) values from the Minolta® Chroma Meter system.



Albumen Height

The albumen height and the adjusted Haugh Unit values (accounting for differences in egg weight) are routinely measured. The albumen height is measured midway between the edge of the yolk and the thick egg white, using an electronic sensor device. Albumen quality is very important in markets where raw egg consumption is customary. Also, Haugh Units are used as a global indicator of egg freshness. Eggs with higher albumens and greater Haugh Unit values can be stored for a longer time while still maintaining their fresh appearance when used by the consumer.



Egg and Yolk Weight, Percent Yolk and Egg Solids

Total egg and yolk weights are measured using high precision scales. It is well recognized that the yolk, being rich in fat, contains most of the total solids of the egg. Therefore, indirect genetic selection for solids is accomplished by increasing relative yolk size.

Dry matter percentage is measured in individual egg samples by separating the egg into its main components - shell plus membranes, yolk and albumen. Each component is weighed and then samples of albumen and yolk are dried. This process is an excellent benchmarking tool to assess and monitor commercial products for the total solid content of their eggs.

The formation of the egg is a fascinating part of the chicken's unique role in feeding the world's growing appetite for affordable protein and nutrition. Perhaps we take for granted the complicated process to produce a quality egg and the number of factors that affect the quality of the final product. Flock health, management, diet and genetic selection all play an important role in achieving the highest quality product for the egg industry's customers.