Egg shell quality and egg internal quality are of major importance to the egg industry worldwide. This review covers the formation of the hen’s egg and ways of measuring egg shell quality and egg internal quality. Egg shell quality may be measured as egg size, egg specific gravity, shell colour, shell breaking strength, shell deformation (destructive or non-destructive), shell weight, percentage shell, shell thickness, and shell ultrastructure. New methods emerge from time to time. Egg internal quality is measured as yolk colour, the integrity of the perivitelline membrane, and albumen quality. Factors that affect egg shell quality and egg internal quality are reviewed. The complexity of the process of egg shell formation means that imperfections can arise in a number of places in the oviduct of the hen. Egg shell quality may be affected by the strain and age of hen; induced moult; nutritional factors such as calcium, phosphorus, vitamins, water quality, non-starch polysaccharides, enzymes, contamination of feed; general stress and heat stress; disease, production system, or addition of proprietary products to the diets. Egg internal quality may be affected by storage; hen strain and age; induced moult, nutrition, and disease. An understanding of the range of factors that affect egg shell quality and egg internal quality is essential for the production of eggs of high quality.

Key words: laying hens, egg shell quality, egg internal quality, albumen, Haugh Units

Introduction

For the egg industry worldwide, the production of eggs which are of good egg shell quality and good internal quality is critical to the economic viability of the industry.
Problems with egg quality currently cost the industry many of millions of dollars per year. Therefore, it is of great importance to understand the factors that affect egg shell quality and egg internal quality. The hen’s egg consists of the yolk (30–33%), albumen (approximately 60%) and the shell (9–12%) (Stadelman, 1995) (see Figure 1). It is sold commercially as shell egg, egg product or as components derived from eggs.

**Formation of the Hen’s Egg**

The egg of the laying hen is the end product of a complicated series of processes which are outlined in detail in Solomon (1991) and Johnson (2000). The first step is the ovulation of the yolk (with associated ovum) from the left ovary into the left oviduct (see Figure 2). The right ovary and oviduct do not develop in the commercial laying hen. The yolk is captured by the infundibulum where the developing egg remains for about 15 minutes and it is here that the formation of the perivitelline membrane and chalazae occurs. In breeder birds, fertilization also occurs in this region of the oviduct.

The egg then moves into the magnum where it remains for about 3 hours while the egg white (albumen) proteins (about 40% in all) are produced. The layer of proteins provides mechanical and bacterial protection for the yolk as well as creating a template for the later formation of the shell membranes and shell. Next the developing egg passes into the isthmus which, over about one hour, produces the fibres that make up the inner and outer shell membranes. The egg then enters the tubular shell gland where water and electrolytes enter the albumen (a process called “plumping”) and the formation of the mammillary cores commences, over a period of approximately 5 hours. The longest time during egg formation is spent in the shell gland pouch (at least 15 hours) and it is here that the egg shell is formed and the process of “plumping” is completed.

The organic matrix of the egg shell consists of the shell membranes, the mammillary cores, the shell matrix and the cuticle. The inorganic portion of the egg shell consists of calcium carbonate. The different layers of the egg shell: the
mammillary knob layer, palisade layer and surface crystal layer are made up of calcite crystals of different orientations (see Figure 3). The fine structure of the avian egg shell is described in Nys et al. (1999), Roberts and Brackpool (1995) and Solomon (1991). Recent evidence suggests that it is the formation of the organic matrix that determines the rate of formation of the egg shell and the termination of shell formation (Nys et al., 1999; Lavelin et al., 2000). Finally, the egg is laid via the vagina and cloaca.

The complex nature of the process of formation of the internal components of the egg and the egg shell mean that quality problems may arise at any of several stages during the formation of the egg. Also, problems with egg internal quality and egg shell quality may result from a combination of factors, rather than from a single factor. However, research has identified a number of factors that are known to adversely affect egg quality.

**Egg Shell Quality**

**MEASUREMENT OF EGG SHELL QUALITY**

Egg shell quality may be measured in a number of ways. Some of these methods necessitate the destruction of the egg. In addition, some methods are direct whereas others are indirect (Hamilton, 1982). Direct methods include measures of shell breaking strength such as impact fracture force, puncture force or quasi-static compression. Indirect means include specific gravity, non-destructive deformation, shell thick-
ness and shell weight. Direct and indirect measurements of shell strength can also be considered as mechanical and physical properties of the egg, respectively (Hammerle, 1969).

In commercial operations, eggs are either candled using light to detect cracks and other defects or they pass through an electronic crack detector for detection of cracks. Experimentally, egg shell quality may be measured by a number of means and there is some equipment available commercially to assist with these measurements, such as the egg quality equipment produced by Technical Services and Supplies that is used in the author’s laboratory.

The specific gravity of the whole egg may be measured by immersing eggs in salt solutions of different specific gravity to see at what concentration of solution they float. Alternatively, special equipment can be used based on Archimedes principle (Pym, 1969). However, a number of authors have raised questions as to the validity of the use of egg specific gravity as a measure of egg shell quality (Sloan et al., 2000; Voisey and Hamilton, 1977a; Wells, 1967a, b). At best, it is an indirect indicator of the amount of shell present in relation to the size of the egg.

Shell colour may be monitored by visual comparison with a series of graded standards or it may be measured by shell reflectivity, which is detection of the proportion of incident light that is reflected from the surface of the egg, under controlled conditions.

Egg weight is easily measured by a suitable balance.

The measurement of shell breaking strength and shell deformation (either destructive or non-destructive) requires the use of special equipment. Shell breaking strength is most commonly measured by quasi-static compression where the egg is compressed under controlled conditions until the shell cracks or breaks (Tyler, 1961). The minimum force required to cause failure of the shell is then recorded. Studies have shown a strong negative correlation between shell breaking strength measured by

![Diagram of Egg Shell Layers](image-url)
quasi-static compression and the percentage of cracks (Wells, 1967a). Shell deformation may be non-destructive where the deflection of the shell under a given force is measured, or it may be destructive and measured as the distance the shell is compressed before it fails (Voisey and Hamilton, 1977b).

The amount and thickness of the egg shell have been found to be related to egg shell strength. Shell weight may be measured by breaking open an egg, carefully rinsing the pieces of shell, drying them and then measuring shell weight. The shell weight can then be calculated as a proportion of egg weight to give percentage shell. Shell thickness may be measured by a suitable gauge and is usually measured on three pieces of shell taken from around the equator of the egg. In the author’s laboratory, a gauge based on a Mitutoyo Model 2109–10 Dial Comparator Gauge, mounted on a frame, is used to measure shell thickness.

The strength of an egg shell is determined not just by the amount of shell that is present, but also by the quality of construction of the shell. Studies of the quality of construction are conducted by examining the ultrastructure of the egg shell under the scanning electron microscope, as described by Solomon (1991), Roberts and Brackpool (1993–94; 1995) and Nys et al. (1999). In circumstances where shell weight, percentage shell and shell thickness are good but shell breaking strength is relatively poor, the explanation probably lies with the shell ultrastructure, or how well the shell has been constructed.

New techniques, such as the measurement of dynamic stiffness of the eggshell, are being developed all the time and compared with the more traditional measurements of egg shell strength (de Ketelaere et al., 2002). These authors point out that the different measures of egg shell strength are measuring slightly different things.

FACTORs AFFECTING EGG SHELL QUALITY

Bird Strain

As a result of genetic selection, different strains of laying hen vary significantly in egg shell quality, egg size and production (Curtis et al., 1985) and there are clear differences between modern commercial birds and traditional breeds of laying fowl (Hocking et al., 2003). Selection for one characteristic such as production or egg weight can affect other characteristics of the hen such as egg shell quality (Poggenpoel et al., 1996). Genetic selection programs need to monitor a range of characteristics to ensure that improvement of one characteristic is not at the expense of other equally important traits.

Bird Age

A number of studies have shown that egg shell quality decreases as birds grow older (Nys, 1986; Roland et al., 1975; Roland, 1979; Roberts and Ball, 2004). Egg size increases with increasing hen age at the same time as shell weight increases or stays the same. Either way, the increase in egg weight is not accompanied by a proportional increase in shell weight so that the ratio of shell weight to egg weight (often referred to as percentage shell) decreases. There is some evidence that the inability of the hen to produce an increased amount of egg shell is related to the activity of 25-hydroxycholecalciferol-1-hydroxylase, an enzyme involved in calcium homeostasis (Joyner et
Dietary manipulations that decrease egg size may improve egg shell quality in older hens (Keshavarz, 2003b) and some supplements are effective in improving egg shell quality in aging hens (Mabe et al., 2003).

Moult
The effect of aging on egg shell quality can be reversed to some degree by the process of induced moulting (Ahmed et al., 2003; Berry, 2003). Results are variable depending on the nature and severity of the moult and the age of the birds. Roland and Brake (1982) reported that the benefits did not last long in older birds and other workers refer to the relatively transient nature of the improvements in shell quality (Lee, 1982; Abu-Serewa and Karunajeewa, 1985; Karunajeewa et al., 1989; Al-Batshan et al., 1994).

Nutrition
Each egg shell contains up to 3 grams of calcium. Therefore, the diet of hens must contain adequate calcium in a form that can be utilised efficiently. There is conflicting evidence about the use of particulate calcium although the consensus appears to be that 50–70% of the calcium should be in the form of coarse (2 to 5 mm diameter) particles and the remainder in powder form (Nys, 1999). The provision of larger particles (e.g. shell grit) has been shown to have beneficial effects but is not always compatible with automated feeding systems. Some authors recommend a mixture of ground limestone and oyster shell (Richter et al., 1999). Inadequate dietary phosphorus may cause demineralisation of the skeleton in the laying hen. The ratio of calcium to phosphorus in the diet is important as high levels of phosphorus may interfere with the absorption of calcium from the gut, resulting in reduced shell quality (Boorman and Gunaratne, 2001). Calcium and phosphorus requirements appear to be influenced by the age of the birds, amongst other things (Bar et al., 2002; Sohail and Roland, 2002). In addition, environmental considerations have resulted in pressure to minimise levels of phosphorus in the diets, especially in some densely populated countries.

The levels of calcium in feed need to be increased during the rearing period, 7 to 10 days prior to the appearance of the first egg (Roland and Bryant, 1994). There is some evidence that provision of additional calcium too soon can result in negative effects on the kidneys if the levels of phosphorus are low (Rao et al., 1992). However, more importantly, if additional calcium is not provided early enough, there may be long-term negative effects on calcium metabolism and bone stores of calcium (Nys, 1999; Roland and Bryant, 2000).

Vitamins such as Vitamin D are necessary for calcium metabolism and must be included in the diet (Hurwitz, 1987). The vitamin D metabolite 25-hydroxyvitamin D 3 (which is converted into the biologically active form of vitamin D3 inside the bird) is now commercially available and may prove valuable under some circumstances. Adequate levels of vitamin C are essential for normal good health and may also help to alleviate the effects of stress (Daghir, 1995b). There is also evidence that supplemental vitamin E assists under conditions of heat stress (Bollengierlee et al., 1998). Low levels of vitamin A may increase the incidence of blood spots, which reduce the internal quality of the egg (Becker and Bearse, 1973, cited in Pingel and Jeroch, 1997).
Water quality may influence egg shell quality. Water containing high levels of electrolytes (saline drinking water) may have long-term negative effects on egg shell quality (Balnave and Yoselewitz, 1987). However, the imported strains of laying hen do not appear to be as susceptible to this effect as are the Australian-bred strains (Chen and Balnave, 2001). The water supplied to birds must also be hygienic to ensure that disease is not transmitted by this route. The temperature of the water provided to laying hens is also important, especially during hot weather. It appears that hens reduce water intake or may even cease to drink, if the water gets too hot. Studies have shown that provision of cool drinking water can improve egg shell quality in heat-stressed hens (Glatz, 1993).

Diets containing high levels of non-starch polysaccharides (NSPs) increase gut viscosity, hold a large amount of water and cause watery and sticky droppings. The use of NSP-degrading enzymes have been used for some time in broiler diets, to alleviate these problems (Choct and Hughes, 1997). In recent years, feed enzymes have been added to the diets of laying hens, mainly in an attempt to reduce the incidence of wet droppings and the consequent management problems. A study conducted at the University of New England found that addition of commercial enzyme preparations to poultry feed not only improved the moisture content of droppings under some circumstances, but also resulted in improved egg shell quality for wheat-and barley-based diets (Roberts et al., 1999). However, this study also found that the addition of the enzymes caused some lightening of the colour of the egg shells of brown egg layers and a reduction in Haugh Units. These potential negative effects need to be monitored during any use of feed enzymes for laying hens.

Phytase is used in poultry diets to release phytate-bound phosphorus and reduce phosphorus levels in effluent. Phytase supplementation has been shown to improve egg shell quality, and the effects of phytase supplementation are modified by the levels of calcium and nonphytate phosphorus in the diet (Hatten et al., 2001; Jamroz et al., 2003; Keshavarz, 2003a; Lim et al., 2003). Australian poultry diets typically contain up to 10% meat meal so that phosphorus is not usually limiting. However, recent evidence of synergistic effects of phytase and xylanase in wheat-based broiler diets (Ravindran et al., 1999), warrants consideration of use of phytase in Australian layer diets. In addition, the possibility exists that less meat meal will be used in poultry diets in the future.

Contamination of feed with mycotoxins has the potential to reduce production and egg shell quality. However, it is likely that these effects are mediated via a reduction in feed intake of the contaminated feed (Suksupath et al., 1989). Some hens, as the result of possessing an inherited gene, accumulate significant amounts of trimethylamine (TMA) in eggs, resulting in an unacceptable fishy odour. The cause is the inability of the hens to oxidise the TMA contained in feed ingredients such as rapeseed meal and fish meal (Pingel and Jeroch, 1997).

**Stress**

**General Stress**

A range of types of general stress can affect egg shell quality. High population
densities were shown some time ago to increase the production of body-checked eggs (Dorminey et al., 1965). Body-checked eggs are thought to result from contraction of the shell gland while the egg shell is in the early stages of formation. Stress can also induce delays in the timing of oviposition when hens retain their eggs and this can result in an increased incidence of white-banded and slab-sided eggs (Reynard and Savory, 1999). The white-banded egg is the one that is retained beyond the normal oviposition time while the slab-sided egg is the one that entered the shell gland while the first egg was still there. The stressors of relocation, or exclusion from nest boxes of birds that normally had access to them, can cause an increase in the incidence of calcium “dusted”, white-banded, slab-sided and misshapen eggs (Hughes et al., 1986; Reynard and Savory, 1999). Even handling of birds which are not used to handling can increase the incidence of cracked eggs (Hughes and Black, 1976). Many of the deleterious effects of general stress on egg quality can be induced by injections of adrenaline (Hughes et al., 1986; Solomon et al., 1987).

Heat Stress

The high temperatures experienced in most parts of Australia and also in other countries during the summer can result in smaller eggs and reduced shell quality via a number of physiological processes occurring within the bird (for example, Usayran et al., 2001). Heat stress reduces feed intake and limits the availability of blood calcium for egg shell formation. It may also reduce the activity of carbonic anhydrase, an enzyme which results in the formation of bicarbonate which contributes the carbonate to the egg shell (Balnave et al., 1989). Therefore, sodium bicarbonate supplementation during heat stress may improve egg shell quality (Altan et al., 2000). Feeding practices in hot weather should focus on ensuring that birds are receiving adequate levels of essential nutrients (Daghir, 1995a). Diets need to be formulated to match feed consumption and it should be recognised that birds will tend to eat most during the cooler times of the day. The addition of fat to the diet during hot weather has beneficial effects, apparently via a number of mechanisms (Daghir, 1995a).

The form of calcium provided probably affects the ability of the birds to produce good quality egg shells under hot conditions and it appears that the provision of about half the dietary calcium in a coarse particulate form can improve egg shell quality in heat stressed birds. However, there is no evidence to suggest that increasing the calcium level of the diet above that necessary to achieve an adequate intake of calcium has any beneficial effect (Nys, 1995, 1999). It appears that the phosphorus requirement of laying hens increases slightly at hot environmental temperatures (Garlich et al., 1978, cited in Nys, 1995). Other dietary remedies that have been tried to alleviate the negative effects of heat stress include addition of sodium bicarbonate to the diet (Balnave and Muheereza, 1997) and supplementation of dietary electrolyes and addition of aluminosilicates. However, the results of using these additives have been variable (Nys, 1995). As already mentioned, the provision of cool drinking water can alleviate the effects of heat stress.

Disease

A number of diseases have been reported to affect egg shell quality. Any disease
that compromises the health of the bird may result in defective eggs and egg shells by indirect means. Spackman (1987) reviews a range of diseases and their effects on egg quality and an excellent summary of avian diseases is contained in Charlton et al. (2000). Any pathogenic agent that grows in the tissues of the reproductive tract can cause problems with egg shell formation. Infectious bronchitis has been reported to cause egg shells to be paler in colour and sometimes wrinkled in appearance. Egg drop syndrome, as well as causing drops in production may also result in paler coloured egg shells and other deformities such as soft-shelled eggs or rough shells (Charlton et al., 2000). Other diseases that may cause production drops are Newcastle disease, avian influenza, avian encephalomyelitis and \textit{Mycoplasma gallisepticum} (Charlton et al., 2000).

\textit{Production System}

The type of production system may influence egg shell quality. However, early problems with cracked eggs in furnished cages have been greatly improved by changes in design of the furnished cages to include egg saver wires and long nest curtains (Wall and Tauson, 2002). Direct comparisons among the different types of production system (e.g. cage, barn, free range) have been made difficult by the shortage of experiments in which all other variables have been maintained constant. Some of the problems with egg shell quality reported from free range systems (Fraser and Bain, 1994) may result from an inability to ensure a balanced diet for the hens. Some studies have found effects of cage density on egg shell quality (Mench et al., 1986) whereas others report no consistent effects (Lee and Moss, 1995).

\textit{Proprietary Products}

Some minerals are necessary in small quantities. These include zinc and manganese which act as cofactors or activators for enzymes that are involved in egg shell formation. The form in which these trace minerals are ingested influences the efficiency with which they can be utilised by the laying hens (Mabe et al., 2003). Proprietary products are available that provide the minerals in forms which improve their availability to the birds. Examples of these products are EggShell 49 (Alltech), Iron Egg (All Farm Animal Health, Australia) and EggBooster (ProPoultry Australia-distributor for Zinpro Animal Nutrition). It would be expected that trace minerals provided in such a form would result in improved egg shell quality. However, it is not always possible to demonstrate improvements (Dale and Strong, 1998; Tangkere et al., 2001) so the additional costs of such products require careful consideration in relation to the potential benefits.

\textit{Egg Internal Quality}

\textbf{MEASUREMENT OF EGG INTERNAL QUALITY}

The interior of the hen’s egg consists of the yolk and the white or albumen. Egg internal quality is measured in several ways. A good quality egg should be free from internal blemishes such as blood spots, pigment spots and meat spots. Some commercial grading machinery allows for detection of these defects. Yolk quality is also a component of the internal quality of the egg. There are two components to yolk quality,
the colour of the yolk and the strength of the perivitelline membrane which surrounds the yolk. If the perivitelline membrane is weak (as in an old egg), the yolk will break more easily (Kirunda and McKee, 2000). Yolk colour preference varies considerably depending on the part of the world and pigments of either natural or synthetic origin may be added to achieve a desired yolk colour. In Australia, the preferred yolk colour is about 11 on the Roche scale. However, other countries prefer darker or lighter yolk colour. Some countries such as Sweden do not allow the use of synthetic pigments.

The quality of the albumen is usually measured from the height of the albumen at a distance of 1 cm from the edge of the yolk. Albumen height is usually converted into Haugh Units, based on the following calculation of Haugh (1937):

\[
\text{H.U.} = 100\log\left[H \times \sqrt{\frac{G}{W}} \times (30W^{0.37} - 100) + 1.9\right]
\]

H.U. = Haugh units
H = albumen height in mm
G = 32.2
W = weight of whole egg in grams

However, the validity of the Haugh Unit has been questioned (Silversides, 1994; Silversides and Villeneuve, 1994; Silversides and Scott, 2001) because it is influenced by the age and strain of bird and is affected by storage.

COMPOSITION OF ALBUMEN

Albumen height and Haugh Units measure the viscosity of the thick albumen. However, current problems in Australia with internal quality often involve a very low viscosity of the thin albumen. Egg albumen is about 12% protein of which the main ones are ovalbumin (54%), ovotransferrin (13%), ovomucoid (11%), \(\alpha\)- and \(\beta\)-ovomucin (1.5–3.0%) and lysozyme (3.5%) (Johnson, 2000). All except lysozyme are glycoproteins. It is known that there are many minor proteins in albumen but few of these have been identified. Robinson (1987) and Li-Chan and Nakai (1989) provide a comprehensive review of the components of egg albumen and changes that occur during storage.

FACTORS AFFECTING EGG INTERNAL QUALITY

Little is known about the way in which the components of albumen interact, although interactions between ovomucin and lysozyme have been suggested. The changes that occur when albumen becomes less viscous are still poorly understood but ovomucin appears to play a major role and ovalbumin is probably also involved (see Li-Chan and Nakai, 1989). Leeson and Caston (1997) speculate that low viscosity thin albumen may result from eggs spending longer than normal in the shell gland (i.e. by egg retention) and therefore taking up more water, although this correlation has not been demonstrated.

Many factors are reported to affect Haugh Units: storage time and temperature, hen age, strain of bird, nutrition (dietary protein and amino acid content e.g. lysine, methionine, feed enzymes, grain type/protein source), disease (IB), supplements (ascorbic acid, vitamin E), artificial exposure to ammonia, induced moult, medication
(e.g. Sevin). It is likely that these factors interact in affecting albumen height and Haugh units. There is some evidence that the mechanisms by which albumen quality deteriorates are different between changes occurring during egg storage and changes resulting from other factors (Toussant and Latshaw, 1999).

### Storage

The effects of storage time and temperature on albumen quality are well-documented (see Stadelman and Cotterill, 1995). Albumen height and Haugh units decrease with storage time and this decrease occurs more quickly at higher temperatures. Rapid cooling of eggs with carbon dioxide was found to improve Haugh Units of stored eggs (Keener et al., 2000). During storage of eggs, the pH of the albumen increases and this is thought to be related to the deterioration of albumen quality. Exposure of fresh broiler eggs to varying concentrations of ammonia resulted in a significant linear relationship between pH and albumen height (Benton and Brake, 2000). The changes occurring in albumen quality during egg storage appear to be related to changes occurring in ovomucin, particularly the thick albumen (Kato et al., 1970, 1981; Toussant and Latshaw, 1999).

During egg storage, the quality of the vitelline membrane declines, making the yolk more susceptible to breaking (Kirunda and McKee, 2000).

### Hen strain and age

The age of the hens is also important as albumen quality declines with bird age (Baker and Vadehra, 1970; Roberts and Ball, 2004; Silversides and Scott, 2001). Albumen quality is affected by the strain of bird and genetic selection (Scott and Silversides, 2000; Tharrington et al., 1999; Toussant and Latshaw, 1999).

### Induced Moul
t

Albumen quality in older hens has been shown to improve following an induced moul (Tona et al., 2002).

### Nutrition

A number of nutritional factors have been reported to affect albumen quality although Williams (1992) concluded that albumen quality is not greatly influenced by bird nutrition. Nevertheless, there are reports of albumen quality decreasing with increasing dietary protein and amino acid content (Hammershoj and Kjaer, 1999), increasing with increased dietary lysine concentration (Balnave et al., 2000), decreasing with the dietary addition of neem kernel meal (Verma et al., 1998), increasing with ascorbic acid supplementation (Franchini et al., 2002) and increasing with vitamin E supplementation, especially at high ambient temperatures (Kirunda et al., 2001; Puthpongsiriporn et al., 2001). Different types or cultivars of grains such as pearl millet (Abd-Elrazig and Elzubeir, 1998) or wheat (Roberts et al., 2002) can also affect albumen quality.

### Ingestion of contaminants

Ingestion of crude oil resulted in lower Haugh Units in poultry (Ekweozor et al., 2002). Vanadium has also been shown to reduce albumen quality by reducing the amount of crude ovomucin per millilitre of thick egg albumen (Toussant and Latshaw, 1999). The ovomucin content of the thin albumen was not affected by vanadium...
supplementation of the diet.

**Disease**

The main disease of laying hens that has been reported to affect albumen quality is infectious bronchitis virus which may cause a decrease in quality and more variable albumen quality (see Spackman, 1987). There is evidence that infectious bronchitis impairs the synthesis of albumen proteins in the magnum of the oviduct (Butler et al., 1972) and is associated with histological changes in the epithelium of the magnum (Davidson, 1986).

**Conclusion**

As seen above, many factors can affect egg shell quality and egg internal quality. An awareness of this range of factors allows an egg producer to monitor eggs and optimise egg quality. Good management and best practice with respect to bird husbandry, careful egg collection, handling and processing all contribute to the quality of the final product.

**References**


Boorman, KN and Gunaratne, SP. Dietary phosphorus supply, egg-shell deposition and plasma
Butler, EJ, Curtis, MJ, Pearson, AW and McDougall, JS. Effect of infectious bronchitis on the
structure and composition of egg albumen. Journal of the Science of Food and Agriculture
Chen, J and Balnave, D. The influence of drinking water containing sodium chloride on
Choc, M and Hughes, RJ. The nutritive value of new season grains for poultry. Recent Advances
in Animal Nutrition in Australia 1997, University of New England, Armidale, NSW 2351,
Curtis, PA, Gardner, FA and Mellor, DB. A comparison of selected quality and compositional
Daghir, NJ. Nutrient Requirements of Poultry at High Temperatures. In : Poultry Production in
Daghir, NJ. Replacement Pullet and Layer Feeding and Management in Hot Climates. In :
Dale, N and Strong, CF. Inability to demonstrate an effect of Eggshell #49 on shell quality in
Davidson, MF. Histological studies of changes in the magnum of the domestic hen associated
De Ketelaere, B, Govaerts, T, Coucke, P, Dewil, E, Visscher, J, Decuyper, E and De
Baerdemaecker, J. Measuring the eggshell strength of 6 different genetic strains of laying
Dorminey, RW, Jones, JE and Wilson, HR. Influence of cage size and frightening on incidence
Ekweozor, IKE, Granville, AW, Nkanga, EE and Ogbalu, OK. The effects of crude oil
contaminated feeds on the yield and quality of eggs of poultry birds (Gallus domesticus).
Elaroussi, MA, Forte, LR, Eber, SL and Biellier, HV. Calcium homeostasis in the laying hens. 1.
Franchini, A ; Sirri, F ; Tallarico, N ; Minelli, G ; Iaffaldano, N ; Meluzzi, A. Oxidative stabili-
ty and sensory and functional properties of eggs from laying hens fed supranutritional doses
Fraser, AC and Bain, MM. A comparison of eggshell structure from birds housed in conventional
battery cages and in a modified free range system. Proceedings of the 9th European Poultry
Glatz, PC. Cool drinking water for layers and broilers in summer. Proceedings of the 9th
Australian Poultry and Feed Convention, Gold Coast, Australia, 202–205. 1993.
Hamilton, RMG. Methods and factors that affect the measurement of egg shell quality. Poultry
Hammerle, JR., An engineering appraisal of egg shell strength evaluation techniques. Poultry
Hammershoj, M and Kjaer, JB. Phase feeding for laying hens : effect of protein and essential
amino acids on egg quality and production. Acta Agriculturae Scandinavica Section A—
Hatten, LF, Ingram, DR and Pittman, ST. Effect of phytase on production parameters and
nutrient availability in broilers and laying hens : A review. Journal of Applied Poultry
Haugh, RR. Egg Quality. The U.S. Egg and Poultry Magazine September 1937, pp. 552–555,
572–573. 1937.


Roland, DA and Bryant, M. Feed consumption, energy consumption, shell quality, egg produc-


Roland, DA, Sloan, DR and Harms, RH. The ability of hens to maintain calcium deposition in the egg shell and egg yolk as the hen ages. Poultry Science 54 : 1720–1723. 1975.


Verma, SVS, Gowda, SK and Elangovan, AV. Response of single comb White Leghorn layers to


