Fatty acid composition of fats

The composition of fats of animal origin depends on the species of animal and in the different tissues and is also influenced to some extent by the diet. Fats of plants, fish and birds are more highly unsaturated due to the presence of varying amounts of linoleic and linolenic in addition to the unsaturated oleic acid than those of mammals. Within individual animals subcutaneous fats contain a higher proportion of undated than the fat from the liver of same mammalian species. The physical nature of fat varies between animals, marine mammals in order to maintain a degree of malleability at the temperature of the tissue.

The fats in the ruminant body are highly saturated due to considerable hydrogenation of unsaturated dietary fats occurring in the rumen. Ruminant lipids contain small amounts of odd-length and branched-chain fatty acids, which are products of microbial metabolism. Ruminant milk fat contains a considerable percentage (20%) of short. Chain fatty acids (2–8 Carbon atoms). Hence ruminant milk fat is softer than the body fats.

Essential Fatty acids:

Despite the fact that certain lipids are essential constituent of animal tissues, the knowledge that carbohydrate can be converted to fat and that some of the lipids constituents like phospholipids, cholesterol can be synthesised, led to the belief that lipids as such are not required in the diet. Later investigations showed that rats on a completely fat free diet, developed a scaly condition of the skin and necrosis of the tail. Failure of growth occurred and even death resulted. Harmful effects on reproduction and lactation performance were also noted. Addition of small amount of linoleic acid was strikingly effective in preventing and curing the disease. Saturated acids were not effective. Later, arachidonic and Linolenic and Linoleic are commonly referred to as essential fatty acids. Though the body can synthesis unsaturated fatty acids, it is suggested that the body does not have enzyme system to synthesise unsaturated fatty acids with 2 or 3 double bonds.

Though these acids are referred to as essential fatty acids (EFA) there is possible intra conversion between them. There is species variation as regards to the extent of intraconversion. In rat, either linoleic or Arachidonic will serve as precursor for the other two. In chick linolenic is convertible to the other two.

Essential fatty acids are required by chicks, calves and goats. Only linoleic acid is an essential nutrient for chicken. A deficiency of essential fatty acids is not common in practical
diets. Excessive amounts are not desirable because of the susceptibility of polyunsaturated acids to oxidation.

**Essential fatty acids**

Research indicates that including flax in poultry diets can have positive effects on broiler performance and egg fatty acid profiles. Inclusion of 10 - 20 % flax seed in broiler diets causes less carcass fat and larger leg weights in flax-fed chickens. Additionally, they reported increased omega-3 fatty acids in meat from chickens fed flax diets. In a companion study, fed 15 % flax seed to broilers and determined that dark meat had higher levels of ALA than white meat, with meat from flax-fed broilers higher in omega-3 fatty acids, compared with meat from chickens fed the control diet. Eggs can be enriched with ALA easily because the fat content of eggs is influenced to a large degree by the laying hen's diet. Egg ALA content increased linearly from 0.26 g/100 g fatty acids in the control diet to 7.07 g/100 g for eggs from hens fed 15 percent whole flax. However, taste panel data noted that eggs from hens fed 10 percent or 15 percent ground flax had lower flavour desirability scores than eggs from hens fed the control diet.

The reduction in the ratio of omega-3:omega-6, caused by a high-corn diet, increased the production of pre-inflammatory mediators, leukotrienes, which can cause laminitis. To alleviate the effects of seasonal pruritus, an equine allergy that causes itchy lesions in horses, Supplementation of 1 lb/1,000 lb body weight of either flax or bran and reported that flax reduced induced allergic reactions. Flax seed feeding can serve as a useful source of nutrients for many classes of livestock. It is high in protein and an excellent source of energy and essential fatty acids. Flax also can be used to fortify foods with omega-3 fatty acids. Research has shown that including flax in livestock diets increases the level of ALA, an essential omega-3 fatty acid, in the resultant meat, milk and eggs. Niche marketing to certain health conscious consumers could be used to add value to food products from flax-fed livestock.

**Protein and Amino acids**

An ideal protein has been defined as one which has a balanced array of amino acids for a specific function. For the growing pig this refers to the pattern of amino acids required to maximise the efficiency of protein synthesis per unit of absorbed protein. Recently, 3 empirical estimates of the ideal amino acid balance required for the growing pig have been published and these estimates are in reasonably good agreement. Whereas the pattern of amino acids which reached the sites of protein synthesis was likely to be close to an ideal balance, it cannot be assumed that this path-tern was the same as that supplied by the diet. In all the studies, the basal protein source comprised natural foodstuffs (barley, wheatings, soya
been meal, fish meal). Consequently, the array of amino acids provided did not necessarily indicate the array of amino acids digested and absorbed. In each experiment, free synthetic amino acids were added to the basal protein. There is evidence that synthetic amino acids may not be efficiently utilised in such diets under limited feeding regimes. Furthermore, in deriving the empirical estimates of ideal amino acid balance none of the studies took account of the ideal level of the nonessential amino acid component.

**Amino acid imbalances**

Amino acid imbalances refer to the deleterious effects that occur when a second-limiting amino acid or mixture of amino acid lacking a particular limiting amino acid is supplemented in diets marginal in one or more indispensable amino acids. In spite of variation in the conditions that have been used to induce amino acid imbalances, such as protein level in the diet, the extent of difference in total nitrogen content between basal and imbalanced diets, and kinds of amino acids used as imbalancing agents, the conspicuous common features of amino acid imbalances have been a decreased concentration of the limiting amino acid in blood, depression of feed intake and weight gain, and increased dietary content of the limiting amino acid needed to correct the imbalances.

There is strong evidence that a decrease in the concentration of a limiting amino acid detected in the anterior prepyriform cortex of the brain is followed by behavioral effects, especially a decrease in feed intake. This might be due to the competition between the limiting amino acid and the amino acids in the imbalancing mixture for transport from blood into brain. One of the biochemical responses of animals fed amino acid imbalanced diets is a rapid decrease in the concentration of the limiting amino acid, which are due in part to an increase in catabolism of the limiting amino acid by the increased activities of enzymes involved in the catabolism of the amino acid. Practically, specific amino acid imbalances could be induced in swine and poultry diets that have been supplemented with lysine, methionine, tryptophan when threonine, isoleucine, valine, etc. are potentially third- or fourth-limiting in diets. In these cases supplementation of the limiting amino acid could be beneficial in preventing the decrease of feed intake that could otherwise occur as a result of amino acid imbalance.

The concept of amino acid balance had been introduced by two pioneering researchers, Osborne and Mendel (1914). They understood that the nutritional value of a protein was dependent upon the proportions of the various indispensable amino acids it contained. The adverse interaction of disproportionate balances of amino acids known as
imbalances, antagonisms, and toxicities, however, **imbalances** refer to the deleterious effects that occur when a second-limiting amino acids or a mixture of amino acids lacking the limiting amino acid is supplemented to diets marginal in one or more indispensable amino acids. The adverse effects of the imbalanced diet may be alleviated by the addition of the most limiting amino acid to the diet.

The current view of amino acid imbalance holds that the decrease of a limiting amino acid in plasma or altered ratio of limiting amino acid to total amino acids is detected in the anterior prepyriform cortex of brain. This is due in part to the competition between the imbalanced amino acids and the imbalancing amino acids for transport from blood into brain. A decrease in the concentration of a limiting amino acid in specific regions of the brain is followed by behavioural effects, especially a decrease in feed intake.

**Amino acid interaction**

Harper reported his categories of amino acid interactions in 1956. He restricted the term amino acid imbalance to cases in which a detrimental effect is observed when a diet low in one or more of the indispensable amino acids was supplemented with other amino acids or protein, and the effects were prevented by a small supplement of the amino acid that is the most limiting. **Antagonism** was defined as those interactions in which the ingestion of excessive amounts of one amino acid increases the requirement for a structurally related amino acid. As in the case of imbalances, the structurally related amino acid must be provided to alleviate the effect of the antagonism. **Toxicities** were defined as a conditions caused by feeding excessive quantities of individual amino acids that are not prevented by supplementing diets with other amino acids or groups of amino acids.

**Amino acid imbalance development of the concept**

The term amino acid imbalance was first used by Hier, *et al.* (1944). They observed growth depression of rats fed a diet containing excessive concentrations of individual amino acids such as glycine, phenylalanine, and proline and attributed the effects to amino acid imbalances. Subsequently, a number of investigators reported that the growth rate of animals fed a low-protein, tryptophan deficient diet was depressed by supplementation of protein sources like corn and gelatin deficient in tryptophan. They also suggested that an amino acid imbalance induced by excessive amounts of other amino acids in the diet increased the requirement for the most limiting amino acid. It was believed that only indispensable amino acids, not dispensable amino acids might induce imbalance. However, amino acid supplements of dispensable amino acids such as alanine, glycine, serine, proline, glutamate,
and aspartate decreased weight gains. Much larger amounts of dispensable amino acids were required to depress growth than needed with indispensable amino acids.

Most of the earlier investigators applied the concept of amino acid imbalance in their research using a variety of low protein diets. With the low protein diets used, imbalances could be produced by adding to the low protein diet a second-limiting amino acid or mixture of individual amino acids lacking the most limiting indispensable amino acid. Generally, the adding method of amino acid mixture tended to consistently induce strong imbalance and maximize associated metabolic changes. However, supplementation of individual or groups of indispensable amino acids in control diets containing adequate dietary protein appeared to show typical consequences of amino acid imbalances. Because responses can occur in conventional poultry at adequate dietary levels of protein, it is likely that amino acid imbalance is a phenomenon that can be important for the practical consideration in animal nutrition.

Even though the supplementation of diets with excessive amounts of amino acids to induce imbalances is not a normal condition, such approaches may provide some information as to which amino acid is suspect under practical conditions. It is more difficult to determine the nature of much subtler imbalances that might occur under conditions of practical nutrition. After the phenomenon of amino acid imbalance was accepted as a general condition in protein metabolism, researchers focused on imbalances of other indispensable amino acids such as threonine, histidine, lysine, isoleucine, and methionine. There has been much interest in the dietary imbalance of threonine in the fact that threonine might be limiting in the diets of several species including humans, rats, pigs, and poultry. These have become useful models for investigations into the physiological and metabolic mechanisms of amino acid imbalance. Isoleucine is the fourth-limiting amino acid in corn for growth of chicks. Isoleucine is potentially limiting in low protein diets for laying hens that have been supplemented with lysine, methionine, and tryptophan. Isoleucine imbalance was readily precipitated by excessive dietary concentration of large neutral amino acids (histidine, methionine, phenylalanine, tryptophane, and tyrosine) in subsequent experiments. Theoretically, any of the dispensable amino acids could be subject to imbalance, however, only histidine, isoleucine, lysine, methionine, threonine, and tryptophan have been used in the studies of amino acid imbalances.

**Occurrence of amino acid imbalance**

The effects of amino acid imbalances induced by disproportionate amounts of amino acids may depend on several factors such as methods of inducing imbalance, species and age
of animal, and difference among optical isomers as imbalancing agents. The effects of amino acid imbalances range from a subtle decrease in the concentration of the most limiting amino acid in plasma to the complete and continued decrease of feed intake and growth rate in animals that can result in mortality.

Amino acid imbalances are most readily inducible in animals fed on diets having low dietary protein contents. Under conditions of low dietary protein, two approaches have been used. First, a relatively small amount supplement of one amino acid to the diet has been used. The supplementing amino acid was often a second-limiting amino acid. Secondly, a relatively large quantity of a mixture of amino acids lacking the limiting one can be used to induce imbalances. This second method usually causes a severe growth depression in a more consistent and reproducible way than the former method. Frequently the mixture is composed of all indispensable amino acids except the one to be imbalanced. Amino acid imbalances that might occur at adequate dietary levels of crude protein would be more interesting since low protein concentration seems unlikely to occur in practical conditions.

**Enzymes involved in amino acid imbalances**

If amino acid catabolism has a role in amino acid imbalances, then an increase in activity of enzymes responsible for the degradation of the first limiting amino acid should be evident in imbalances. For example, branched-chain α-keto acid dehydrogenase (BCKAD), which regulates the irreversible degradation of branched-chain α-keto acids is believed to be the primary regulated enzyme of branched-chain amino acid catabolism. The BCKAD is inactivated by a kinase that, in turn, is allosterically controlled by the concentration of branched-chain α-keto acid and possibly certain other keto acids. Because the precursor amino acids are usually present in imbalancing mixtures of amino acids, isoleucine imbalance were due in part to increased BCKAD activity, leading to the decreased plasma isoleucine concentrations and the increased isoleucine requirement of chicks under conditions of isoleucine imbalance.

**Neural mechanism in amino acid imbalances**

To examine the role of the brain in recognizing the imbalances, the depressed feed intake of rats fed an imbalanced diet could be restored by the infusion of a small amount of the most limiting amino acid into the carotid artery a few hours before feeding the imbalanced diet, whereas a similar amount of the same amino acid infused into the jugular vein had no effect on feed intake. This study suggests that the concentration of limiting amino acid in blood supplying the brain determines the feed intake changes in animals fed amino acid imbalanced diets. Amino acid imbalance indicating that the concentration of limiting
amino acid was found to be decreased in specific sites of brain, such as the anterior prepyriform cortex, anterior cingulated cortex, locus ceruleus, and nucleus of solitary tract among 14 microdissected brain areas when an imbalanced diet was fed to rats.

The role of the anterior prepyriform cortex in the imbalances which is the consumption of a threonine-imbalanced diet was increased in rats by the injection of 2 nmol threonine into the prepyriform cortex. Injection of 4 nmol into the prepyriform, however, did not result in a significant increase of feed intake even though both injections of threonine into the prepyriform of rats reversed their selection of a protein-free diet in favor of a threonine imbalanced diet. It can be said that the presence of the limiting amino acid in the prepyriform exerts its effects separately on dietary selection and on quantitative intake of an imbalanced diet, depending on the dose level of the limiting amino acid. It would thus appear that the anterior prepyriform cortex is important in the initial recognition of amino acid imbalances.

The possibility that amino acid imbalances cause impaired synthesis of neurotransmitters that the concentration of norepinephrine in the prepyriform of rats was decreased by feeding amino acid imbalanced diets. They speculated that specific neurotransmitters had a role in the regulation of feed intake in response to ingestion of imbalanced diets. In other studies, however, the effects of amino acid imbalances were not associated with changes of specific neurotransmitters in brains of rats and chicks. Thus, the role of neurotransmitters in the prepyriform cortex in the recognition of amino acid imbalances needs further studies.

**Nutrient Interactions and Toxicity**

Excess intake of protein exacerbates vitamin B-6 deficiency. The chick studies together with the rat study also provided qualitative evidence that excess protein increases the dietary requirement for vitamin B-6. The protein level from 200 to 400 g/kg, using methionine (Met)-fortified soy-protein isolate, increased the vitamin B-6 requirement for maximal growth by 45%. Vitamin B-6 [as pyridoxal phosphate (PLP)], is intimately involved in sulfur amino acid (SAA) metabolism. In the trans-sulfuration pathway, homocysteine (1serine) conversion to cystathionine, and cystathionine conversion to cysteine, α-ketobutyrate and ammonia require PLP. Of the homocysteine produced from Met catabolism in mammals, an estimated 50% is re-methylated to Met, and roughly half of the homocysteine remethylation that occurs uses 5-methyltetrahydrofolate as a methyl donor. The biosynthesis of serine, with its subsequent conversion to glycine, generates a methyl group, and this PLP-requiring reaction is an important contributor to the folate pool for use in remethylating homocysteine to Met. Thus, in the overall process of transsulfuration, there are
three key PLP-requiring reactions. In addition, several S-adenosylmethionine–requiring reactions also require PLP as a cofactor, e.g., the conversion of ornithine to putrescine, putrescine to spermidine and spermidine to spermine. Moreover, one of the pathways in cysteine catabolism involves transamidation, which is a PLP-dependent reaction. Because vitamin B-6 status can affect the level of both homocysteine and cystathionine in blood and urine, we attempted herein to use the chick as a model for purposes of determining whether excess dietary Met per se might increase the dietary need for vitamin B-6. In a quantitative study involving both vitamin B-6 and Met, the chick is a very useful animal model to that transsulfuration in avian species is similar to that in mammals. Moreover, chicks, unlike rats, do not practice coprophagy, a factor that could confound interactive results of a vitamin B-6 dosing study. It is well documented that an elevation in the circulating level of homocysteine represents an independent risk factor for cardiovascular disease in humans. Thus, if excess Met ingestion caused by high protein diets were to exacerbate vitamin B-6 deficiency, also a factor that causes homocysteinemia, high protein or high Met diets might appropriately be added to the growing list of factors that contribute to cardiovascular disease.

The dietary preferences, gastrointestinal morphology and metabolic capabilities of animals have been intimately intertwined during evolution, and the degree of dietary specialization is extremely variable across the animal kingdom. Omnivorous, or generalist species, consume a variety of plant and animal foods that frequently change in relative proportion. These species possess the digestive and metabolic plasticity to adapt to a wide variation in dietary macronutrient proportions. For example, omnivorous species such as chickens, Japanese quail, rats, pigs and humans are capable of up- or down-regulating enzymes for amino acid catabolism and are able to utilize diets with either very low or very high protein content.

**Egg quality**

The term quality defined as the sum of characteristics of a given food item which influence the acceptability or preference for that food by the consumer. It is clear that egg quality will mean different things to different people and the consumer’s perception of quality is likely to vary depending on their intended use of the egg and their own preferences.

Eggs which do not meet these minimum requirements can only be sold for human consumption if they have been pasteurised and meet the microbiological criteria. Thus although grading systems for shell eggs may vary from country to country or region to region, all of the regardless of the grading or classification system used egg shell quality and interior quality are important factors in determining egg quality.
Egg shell quality

The vast majority of eggs are sold in their shell and a consumer’s first impression of any egg purchased is based on their perception of shell quality.

Egg quality defects

Poultry egg quality defects are broadly classified as external or internal. About 10% of the total eggs produced are downgraded due to external defects while 1% is due to internal defects. External defects include shell quality, cleanliness, shape, texture and soundness. Egg quality defects lower the grade, consumer appeal, storage/shelf life, hatchability, increase egg breakage and cost of packaging. Internal quality defects are in the yolk and albumen. They occur in the form of blood and meat spots, double yolks, mottled and discolored yolks, rotten eggs, watery whites, discolored whites and round worms in eggs. About 5-7% of eggs produced do not reach the consumer; 2-3% of the damage is due to problems during laying and 3-4% during the process after laying.

No single factor is usually responsible for egg quality defects. Factors related to egg quality defects include nutrition, health, flock management, environmental conditions and breeding.

Egg quality is a general term that relates to various external and internal standards that are imposed on the eggs. Egg quality has an influence on egg acceptance or rejection by the consumer. Egg quality defects are deviations in external and internal standards of the egg that affect the quality. Exterior quality includes egg weight, egg shape, colour, shell thickness, shell weight, shell density, texture, egg surface area, and cleanliness. The eggs should be uniform in colour, size and shape. The shell of each egg should be smooth, clean and free of cracks. Egg weight, shape and colour are external characteristics that influence grading, price, consumer preference and hatchability. Poor eggshell quality has been of major economic concern to commercial egg producers. Information from egg grading facilities indicates that 10% of eggs are downgraded due to egg shell quality defects. Internal quality refers to egg white (albumen) cleanliness and viscosity, size of the air cell, yolk shape and yolk strength and involves functional, aesthetic and microbiological properties of the egg yolk and albumen.

Poultry egg as important source of nutrients:

The proportions of components for fresh egg are 32% yolk, 58% albumen and 10% shell. Egg albumen is the clear liquid contained within an egg. Its primary purpose is to protect the egg yolk and provide additional nutrition for the growth of the embryo. It is rich in proteins and contains almost no fat, unlike the egg yolk, which has a high fat value. The egg
**yolk** is the yellow spherical part of an egg that is surrounded by the albumen. It is the part of the egg which feeds the developing embryo. The poultry egg is of a high nutritional value to man that is mainly attributed to egg albumen and egg yolk which are the edible components. They supply all **essential amino acids** for humans, and provide several **vitamins** and **minerals**, including retinol (vitamin A), riboflavin (vitamin B₂), folic acid (vitamin B₉), vitamin B₆, vitamin B₁₂, choline, iron, calcium, phosphorous and potassium. The egg has chemicals and components that have multiple uses in biotechnology, chemical, food, pharmaceutical and art (painting and photography) industries.

In the production of poultry eggs, the aim is to produce eggs with a high hatchability, consumer preference, and of the best grade that fetch the highest price. However, there are certain defects that affect negatively the external and internal quality of the egg causing losses to the producer, retailer and consumer. It is therefore important to understand the external and internal egg defects, their causes and economic importance. Understanding the various egg quality defects and their causes will assist in designing and implementing measures to minimize their occurrence, hence reducing losses in the egg value chain. This paper reviews the egg quality defects, their causes, possible solutions and economic importance.

**Types of Defects**

**External defects**

Exterior measurements (i.e. measurements made without breaking or piercing the shell) have traditionally been done by visual inspection of the outer surface of an intact egg, to search for cracks, and by candling. However, a system with a high precision using a laser scan to detect cracks, pinholes, and thin regions in the shell has been developed. External egg quality defects include shell quality, cleanliness, shape, texture and soundness.

**Shell quality**

To the human eye, the shell of the egg appears to be a homogeneous structure with uniform composition throughout. When observed under high magnification, the structure is extraordinarily complex. It has at least six significantly different layers beginning with two shell membranes between the albumen and the interior surface of the shell. These layers are followed by three regions of calcified materials, and completed with a thin organic material on the outer surface called the cuticle. Within the different layers are crystalline interfaces, hundreds of hidden fault lines, and thousands of pores (tiny tunnels which travel from outer to inner surfaces of the shell). The small amount of organic matter mostly consists of matrix proteins (mixture of proteins and polysaccharides rich in sulphated molecules) and shell
pigment. The matrix proteins are critically important in determining the egg shell structure and serves as foundation for the deposition of calcium carbonate during the mineralization process. Without the matrix proteins, the crystal structure would be too brittle to keep its form.

The chicken eggshell is 95-97% calcium carbonate crystals, 0.3% phosphorous and magnesium and traces of sodium, potassium, zinc, manganese, iron and copper and organic matter. The structure and composition of the avian eggshell serves to protect the egg against damage and microbial contamination, prevention of desiccation, regulation of gas and water exchange for the growing embryo, and provides calcium for embryogenesis. The eggshell should be as strong as possible to maximize the number of eggs reaching the consumer. No single factor is usually responsible for egg shell quality. Factors related to eggshell quality include nutrition (the nutrient balance and intake levels of the ration), health (the flock’s general health and previous health history), flock management and its age, environmental conditions and breeding (the strain and breed of the flock) along with other factors. About 5-7% of eggs produced do not reach the consumer; 2-3% of the damage is due to problems during laying and 3-4% during the process after laying.

**Types of Shell Defects**

They include shell thickness, gross cracks, hairline cracks, star cracks, misshapen egg, pimples, sand paper, pinhole, leatherly and glossy eggs. The complexity of structure of the shell gives rise to differences in breakage in eggs. The crack severity, shape and length are results of variations in the structure with fractures occurring at the points of least resistance. Shell defects account for 0.3-5.6% of total production.

Nutrition plays a key role in maintaining egg quality. The hens should be offered a balanced ration. Vitamin D, calcium, phosphorous, manganese, copper and zinc play a major role in maintaining the integrity and shell quality. Excess or reduced concentration of phosphorous, chlorine, or mycotoxins contamination affects the availability of calcium and vitamin D. Calcium and phosphorus balance is critical for proper egg production and eggshell quality. Layer ration should be formulated with correct amount of calcium and phosphorus (usually 3.5 - 4.0% calcium, 0.35-0.40% phosphorus).

The thickness of the shell is determined by the amount of time it spends in the shell gland (uterus) and the rate of calcium deposition during shell formation. If the egg spends a short period in the shell gland, the thickness will be less. Also, the time of the day when the egg is laid determines the thickness of the shell. In general, the earlier in the day or light portion of the photoperiod, the thicker the shell will be. Intestinal absorption of calcium in the
diet is about 40% when the shell gland is inactive, but reaches 72% when active. This time closely coincides with late afternoon or the dark hours for the layer. Having higher calcium levels in the gut during this time is important to ensure calcium is being taken from the diet and not bone.

Shell quality affects consumer appeal, packaging, egg breakage, storage/shelf life, and hatchability. An egg shell that is smooth is desirable because rough shelled eggs break more easily. Large sized eggs usually break more easily than small ones because the hen is genetically capable of placing only a finite amount of calcium in the shell. Reduction in shell quality lowers egg shelf life, hatchability and increases breakage. Shell thickness and porosity regulate the exchange of carbon dioxide and oxygen between the developing embryo and the air during incubation. Shell thickness has a significant effect on moisture loss during storage and incubation. Thin shelled eggs loose more moisture than do thick shelled eggs, causing difficulty during hatching and deterioration on quality for table eggs.

The shell is formed by the activity of cells lining the oviduct and uterus. Under stress the secretions of these cells become acidic and the cells can be damaged or destroyed. In extreme cases, stress induced effects can result in eggshells that have excess deposits of calcium - a sort of powdery "bloom" on the surface and result in misshapen eggs.

A sudden disturbance to the normal routine may result in a hen retaining the egg within the shell gland area of the oviduct for a longer than normal period. During this time a very thin layer of extra calcium is deposited on the egg, producing a greyish, bleached outlook. Release of stress-related hormones will result in the production of pale brown-shelled eggs. Relocation, such as movement from one type of housing to a completely new housing environment, stresses the hens and can produce severe visual defects of the egg. It is known to increase the incidence of calcium coated and checked (misshapen) eggs.

**Internal defects**

These include defects on the yolk and albumen. Assessment of Interior egg quality involves breaking the egg to inspect its contents. Internal egg defects occur in the form of blood and meat spots, double yolks, mottled and discoloured yolks, rotten eggs, watery whites, discoloured whites and round worms in eggs. Occurrence of blood and meat spots is revealed by candling. Candling reveals most of the spots, but brown eggshell hampers selection in brown chicken lines. Estimated frequency of blood and meat spots in brown layers is about 18% whereas it is 0.5% in white egg layers.

Several factors are known to increase the incidence of meat and blood spots: genetic background, low level of vitamin A and/or D, stress or infections. Internal egg quality
involves functional, aesthetic and microbiological properties of the egg yolk and albumen. Meat and blood spots in addition to being an aesthetic and ethical problem, they may increase the risk of infections such as salmonella and reduce hatchability of eggs. Blood spots are droplets of blood found usually on the surface of the yolk. Meat spots appear as red, brown or white spots in the albumen. They are either pieces of tissue from reproductive organs or blood spots that have changed colour due to dilution. They emerge during the ovulation process in the ovary or later in the oviduct. Blood on the yolk originates from bleeding of the small vessels in the ovary or in the oviduct. Meat spots in the albumen can be formed from a bit of reproductive tissue while the egg is passing through the oviduct. As an egg ages, the yolk takes up water from the albumen, which in turn dilutes blood spots and makes them look like meat spots. In general the frequency of blood and meat spots is less than 1% in all eggs laid in commercial lines.

Different factors, including nutritional, environmental and heredity, trigger the incidence of spots. Probably the most important nutritional factor is a lack of vitamins A and D. When the supply of vitamin A is sufficient, the chicken has a low probability of having blood spots. Environmental factors, like sudden loud noises, temperature changes and infections, induce an increase in the incidence of spots.

Double Yolk eggs appear when ovulation occurs too rapidly, or when one yolk somehow gets stuck before shelling and is joined by the next yolk. Double yolk eggs may be laid by a pullet whose productive cycle is not yet well synchronized. They're occasionally laid by a heavy-breed hen, often as an inherited trait.

A double shelled egg or an egg within an egg appears when an egg that is nearly ready to be laid reverses direction and gets a new layer of albumen covered by a second shell. Sometimes the reversed egg joins up with the next egg and the two are encased together within a new shell. Double shelled eggs are so rare that it is unknown exactly why they happen.

Some eggs may have an unusual or unacceptable odour or taste, although their appearance is normal. They differ from rotten eggs, which are obviously defective and smell putrid. Off odours and flavours are rare in fresh eggs stored correctly. They will occur due to poor storage conditions (long storage period, high temperature, and presence of strongly scented materials in egg store) and use of strongly flavoured ingredients in the feed.

Hens that eat onions, garlic, fruit peelings, fish meal, and fish oil will lay eggs with an undesirable flavor. Eggs can also absorb odors that translate into unpleasant flavors if they're stored near kerosene, carbolic acid, mold, must, fruits and vegetables.
The normal colour of egg white is slightly yellow-green but may be discoloured to yellow, green or pink which is objectionable. However, this problem is rare. Excess riboflavin in the diet causes egg white to turn green while cyclopropene fatty acids in cottonseed cause the white to turn pink after storage. Omission of xanthophylls in the diet will lead to pale yolks. Pale yolks can result from any factor which alters or prevents the absorption of pigments from the diet or the deposition of these pigments in the yolk. The inclusion of more than 5% cottonseed meal in a layer diet will result in olive or salmon coloured yolks. Mottled yolks (with many pale spots and blotches which vary in colour, size and shape), occur when the contents of the albumen and yolk mix as a result of degeneration and increase permeability of the vitelline membrane.

**Egg quality defects**

*Egg shell integrity*

Defects considered under the category of egg shell integrity include gross cracks, hairline cracks, star cracks and thin shelled or shell-less eggs. As cracked eggs cannot be made available for retail sale, high numbers of cracked eggs will have a negative impact on the profitability of any egg producer.

One of the most obvious reasons for egg shell cracks (including gross cracks, hairline cracks and star cracks) is *mechanical damage* caused either by the birds themselves or as a result of poor management practices, such as infrequent collection of eggs, rough handling and poor design and/or maintenance of the cage floor.

Egg shell strength ultimately affects the soundness of the shell, with weaker shelled eggs more prone to cracks and breakages and subsequently microbial contamination. Shell strength can be affected by a wide range of factors including:

*Egg size:* Smaller eggs have stronger shells than larger ones, as hens have a finite capacity to deposit calcium in the shell and as a result, the same amount of calcium is spread over a larger area.

*Age of bird:* Older birds tend to lay bigger eggs and have a higher egg output, which impacts on shell strength as described above. Very young birds with immature shell glands may produce shell-less eggs or eggs with very thin shells. Delaying the onset of sexual maturity by one to two weeks will prevent this.

*Stress:* A single stress or disturbance to a flock of laying hens can be enough to desynchronise the process of egg formation for several days, during which time, a number of different egg quality faults may be seen (MAFF, undated). For example;
• Any factor which results in oviposition prior to completion of shell deposition will result in soft or thin-shelled eggs. Activities which create disturbances in and around the layer shed should be minimised.

• If an egg is retained in the shell gland, any subsequent egg laid may spend less time than normal in the shell gland, resulting in insufficient shell deposition and a soft shelled or shell-less egg.

Elevated environmental temperature: High (above 25°C) environmental or shed temperatures may affect the feed (and therefore calcium) intake of the bird, thus resulting in a decreased availability of calcium for shell deposition. As well as decreasing feed intake, laying hens will try to overcome heat stress by panting. However, this causes a decrease in the amount of carbon dioxide (CO₂) in the hens’ blood, a condition known as respiratory alkalosis. As egg shells are made up of 95% calcium carbonate (CaCO₃), this decrease in blood CO₂ levels, combined with an increase in blood pH and a subsequent decrease in Ca²⁺ ions for shell formation leads to an increase in the number of thin or soft shelled eggs produced.

Nutrition and water quality: The provision of adequate dietary minerals and vitamins is essential for good eggshell quality. Similarly, as water quality varies from country to country and region, the role of drinking water in mineral and trace element supply should not be overlooked.

Calcium and phosphorous are essential macro minerals with calcium forming a significant component of the shell and phosphorous playing an important role in skeletal calcium deposition and subsequent availability of calcium for egg shell formation during the dark period. Effect of calcium levels in drinking water on shell integrity in laying hens and demonstrated that birds supplied an additional 200 mg of calcium per litre of drinking water laid eggs with mean shell strength of 42.6 ± 9.0. This was in comparison to those receiving un-supplemented water, whose eggs had mean shell strength of 38.9 ± 7.0. However, the feeding of calcium levels above the requirement of the bird for production has not been shown to improve shell quality. Indeed, feeding hens high levels of calcium may interfere with the availability of other minerals and can have a negative impact on the ability of the bird to utilise calcium, particularly if calcium levels in the diet are subsequently decreased.

Similarly, feeding high levels of dietary phosphorous have also been shown to have a negative effect on eggshell quality. A clear linear negative correlation between specific gravity and plasma phosphate, it remains unclear whether excess plasma phosphorous interferes with the mobilization of skeletal phosphorous reserves or the shelling process itself or if elevated levels of phosphorous increases calcium excretion, the interaction of
phosphorus and chloride and the role of chloride in egg shell integrity, as with phosphorous, elevated dietary levels of chloride resulted in decreased eggshell quality and lower levels of blood acid-base indicators. An increase in shell defects with no changes in egg production, egg weight, feed or water intake, blood-acid base levels and electrolyte levels for birds provided with 2000 mg of sodium chloride (NaCl) per litre drinking water. This was in comparison to those hens provided with water with 600 mg NaCl per litre. Birds receiving 2000 mg of NaCl per litre drinking water also had an increased incidence of shell-less eggs. Egg shell defects persisted after the sodium chloride was removed from the drinking water. In contrast, hen’s diets low in chloride and found virtually no effect on shell quality. Trace mineral nutrition is a complex area of animal nutrition, and a wide range of interactions and antagonisms can result in poor absorption or utilisation of minerals, essential for shell formation. It should also be noted that not all trace mineral sources are equally available, and consideration should be given to this aspect of premix formulation. The varying amounts of zinc, copper, iron and manganese in the shell and its associated membranes. It is clear, therefore, that provision of adequate levels of these minerals, which are key components of the shell matrix and play an essential role as co-enzymes, is essential if shell integrity is to be maintained.

Vitamin D also plays an important role in the proper utilisation of calcium and phosphorous and sufficient amounts of this vitamin should be included in the feed. Finally, care should be paid to the mixing of the diet. Thorough mixing of the feed is essential if each bird in the flock is to receive a similar amount of any given nutrient. This is particularly true for layer hen diets which frequently contain raw materials with a wide range of different densities.

**Colour**

The colour of an egg shell is determined primarily by the genetics of the hen, with white feathered hens laying white eggs and brown feathered hens laying brown eggs. During the process of egg shell formation in brown egg layers, the epithelial cells lining the surface of the shell gland synthesise and accumulate pigments, such as biliverdin-IX, its zinc chelate and protoporphyrin-IX. In the final three to four hours of shell formation these pigments are transferred to the viscous, protein rich cuticle, the quantity of pigment in the cuticle which determines the colour of the egg. As the cuticle is deposited onto the eggshell at the same time that shell deposition reaches a plateau (approximately 90 minutes prior to oviposition), pigment distribution is not uniform throughout the shell, with very little pigment contained in the shell itself. Thus, any factor which causes a disruption, either in the ability of the
epithelial cells to synthesise pigment or in the deposition of the cuticle, will affect the colour of the egg shell. These factors include:

**Stress:** Epinephrine, a stress hormone, will cause a delay in oviposition and cessation of shell gland cuticle formation, which can cause pale shelled eggs to be produced. Stressors may include, amongst others, high cage density, loud noise and handling.

**Age of bird:** As birds age increases, the intensity of pigment decreases. This may be due to decreasing production of pigment or increased surface area over which available pigment is distributed.

**Chemotherapeutic agents:** Certain drugs have been shown to affect egg shell colour. For example, nicarbazin (an anticoccidial drug) fed at a level of 5 mg per day can result in the production of pale eggs within 24 hours, while higher doses can lead to complete depigmentation. Chlortetracycline (600 - 800 ppm) may also result in yellow egg shells (Beyer, 2005; Hendrix Genetics, undated).

**Disease:** Viruses, which affect the mucus membranes of the respiratory and reproductive tract, such as NCD and IB, not only cause a decrease in egg production, but also cause the shell to become abnormally thin and pale.

**Cleanliness**

Cleanliness is probably the easiest aspect of egg shell quality to control, and good management plays an important role. Most eggs are clean when laid and subsequently become contaminated with faecal material or other contaminants. Defects listed in the EPF Code of Practice, which fall into this category, include cage marks, stained eggs and fly marks.

**Management:** Good management practices will help reduce the number of dirty eggs. These practices include frequent collection of eggs, as well as regular replacement of litter material in nest boxes, or regular maintenance and cleaning of cage floors and roll out trays. Whilst less common, fly stains, water stains and grease or oil stains may occur, and can be prevented by good shed and equipment maintenance or management.

**Nutrition and / or bird health:** Any factor which causes diarrhoea in the birds, (for example high dietary salt levels), will also result in an increase in the number of dirty eggs collected. Blood smears on eggs can be minimised by good pullet management, including weight for age, lighting and beak trimming if necessary.

**Internal egg quality**

Unlike external (shell) quality, internal quality of the egg begins to decline as soon as the egg is laid. Thus although factors associated with the management and nutrition of the
hen do play a role in internal egg quality, egg handling and storage practices do have a significant impact on the quality of the egg reaching the consumer. Similarly, although the shell provides a unique “package” for the distribution of the egg contents to the consumer, it is in fact the internal quality of the egg that is most important to the consumer. These aspects of internal quality are significantly more difficult to observe or evaluate in the intact egg, even with the use of candling. In addition to the, obvious, nutritional quality of the egg, internal egg quality is extremely important because of its many functional and aesthetic properties. For example, eggs are used as thickening agents in custards and puddings; egg whites are used as thickening agents to give icings a desirable texture and egg yolks add colour and richness to food.

In recent years, much attention has been focused on increasing the omega 3:6 ratio and vitamin content of eggs, principally through manipulation of the diet. However, although these “enhancements” further complicate the issue of egg quality, it is beyond the scope of this review to discuss these further.

The internal defects can be broadly categorised into three groups; namely: defects affecting yolk quality, defects affecting albumin quality and defects affecting overall quality.

**Yolk quality**

Yolk quality is determined by the colour, texture, firmness and smell of the yolk.  

*Yolk colour:* Although yolk colour is a key factor in any consumer survey relating to egg quality, consumer preferences for yolk colour are highly subjective and vary widely from country to country. The primary determinant of yolk colour is the xanthophyll (plant pigment) content of the diet consumed. It is possible to manipulate the yolk colour of eggs by the addition of natural or synthetic xanthophylls to layer hen feeds. This ability to readily manipulate egg yolk colour can be an advantage in meeting market demands. However, the ease with which yolk colour can be manipulated can lead to unwanted colour changes. For example, the inclusion of higher than recommended levels or incorrect ratios of pigments can lead to orange-red yolks. Similarly, diphenyl-para-phenylenediamine (DPPD), an antioxidant, has been reported to cause excessive deposition of pigments in the egg yolk. The inclusion of more than 5% cottonseed meal in a layer diet will result in olive or salmon coloured yolks, while the inclusion of certain weeds or weed seeds may result in green yolks. Similarly, inadvertent omission of xanthophylls from the diet will lead to pale yolks.

Both inadequate mixing of the diet as well as excessive mixing of the diet will also result in a heterogeneous feed, and subsequent variation in the amount of xanthophylls
consumed by each hen in the flock. This will result in egg yolk colour not being uniform throughout the flock.

Pale yolks can result from any factor which alters or prevents the absorption of pigments from the diet or the deposition of these pigments in the yolk. Mottled yolks (with many pale spots and blotches which vary in colour size and shape), occur when the contents of the albumen and yolk mix as a result of degeneration and increase permeability of the vitelline membrane. The feeding of gossypol at recommended level but over a long time from cotton seed meal, certain antioxidants such as gallic acid (from grapes, tea and oak bark) and tannic acid, or tannins from grains such as sorghum, calcium deficient diets, storage time and temperature has also been shown to affect the degree of egg yolk mottling.

Yolk firmness: The yolk of a freshly laid egg is round and firm. However, as the egg ages and the vitelline membrane degenerates, water from the albumen moves into the yolk and gives the yolk a flattened shape.

Yolk texture: Rubbery yolks may be caused by severe chilling or freezing of intact eggs, the consumption of crude cottonseed oil or the seeds of some weeds.

Albumin quality

Albumin quality is related to the consistency, appearance and the functional properties. Consistency: Albumin quality is measured in terms of Hough Units (HU) calculated from the height of the albumin and the weight of the egg. Albumin consistency is influenced by:

Age of the hen: HU will decrease with increasing bird age value, with HU decreasing by around 1.5 to 2 units for each month in lay. In an ideal situation, HU should be on average 102 at 20 weeks of age, falling to an average of 74 HU by 78 weeks of age.

Genetics: Strain of bird has also been shown to play a role in albumin consistency, with some strains consistently producing eggs with thin albumin. HU values were more variable within the brown egg layers compared with those that lay white eggs. High producing birds tend to lay eggs with relatively lower amounts of thick albumin and, although this can be influenced by selective breeding, egg numbers are usually considered more important.

Age and storage of the egg: As the egg ages and carbon dioxide (CO₂) is lost through the shell, the contents of the egg become more alkaline, causing the albumin to become transparent and increasingly watery. At higher temperatures, loss of CO₂ is faster and the albumin quality deteriorates faster. Decreasing shed temperatures in the hotter months, combined with regular collection of eggs will help to reduce deterioration of the albumin before collection.
Eggs stored at ambient temperatures and humidity lower than 70% will lose 10 – 15 HU in a few days from point of lay. By 35 days, these eggs will lose up to 30 HU. Storage of eggs at temperatures of 7 – 13°C and a humidity of 50 - 60% (as discussed under mottling), will reduce the rate of degeneration of thick albumen proteins and, consequently, egg albumin quality will be maintained for longer.

**Appearance:** Normal albumin is transparent, with a slightly yellow green colour. Discolouration of the albumin may occur if the eggs are stored for an extended time period in poor conditions, with the albumin becoming much yellower. Cyclopropene fatty acids from cottonseed meal and the certain weed seeds can cause albumin to turn pink after storage. Green whites are caused by excesses of riboflavin (vitamin B_2_) in the diet. Cloudy whites may be caused by the oiling of eggs within six hours of lay.

**Overall quality**

**Blood spots:** Blood spots may vary from indistinguishable spots on the surface of the yolk to heavy contamination throughout the yolk. Although blood spots are normally closely associated with the yolk, occasionally blood may be diffused through the albumin. Blood spots occur when small blood vessels in the ovary rupture when the yolk is released.

**Vitamin deficiency:** Vitamin K plays an important role in blood clotting. Vitamin K deficiency can result in an increased occurrence of blood spots.

**Meat spots:** These are usually associated with the albumin rather than the yolk and often consist of small pieces of body tissue. However, some may consist of partially broken down blood spots or pigments. The occurrence of blood spots varies with strain of bird, increases with age of bird and is reported to be higher in brown egg layers.

Old eggs and eggs stored at high temperatures are more likely to exhibit off odours or flavours. Other causes of off odours or flavours include strongly flavoured feed ingredients such as fish meal or fish oil, some vegetables (including onions, turnips and excessive amounts of cabbage) and rapeseed or canola.

**Hatchability**

Hatchability defined as the proportion of eggs surviving to the end of incubation that hatch. In other words Hatchability is defined as the percentage of eggs surviving to the time of hatching that produce a chick.

**Sociality** is indexed here by the frequency of intra-specific interactions among breeding individuals in a population. Three variables related to sociality were tested for their influence on hatchability.

**Spacing pattern and territoriality**
There is no significant effect of spacing pattern on hatchability. There is a slight trend, however, toward increased hatchability as the territory becomes more all-inclusive with colonial species having the lowest hatchability and those maintaining all-purpose territories the highest.

**Social organization:** the type of social organization has a strong, significant effect on hatchability ($P = 0.01$). Monogamous species have the highest hatchability, followed by polygamous species, and finally by cooperative breeders.

One pattern that emerges from the above analyses is that between hatchability and sociality. In all cases, hatchability decreases with increasing complexity of social structure. There are several largely speculative possible explanations for this trend, four of which will be considered briefly.

1) Increased competition for mates and/or intra-sexual competition during egg laying leads to greater interference and a lower probability those eggs will be fertilized. This hypothesis could in part explain the lower hatchability of polygamous species and of cooperative breeders, for which the opportunities for interference during egg-laying may be greater than in other species. It is also a likely explanation for the lower hatchability.

2) Increased intra-specific interactions result in greater neglect of eggs and, thus, higher embryo mortality.

3) Lack of behavioural synchronization between the sexes results in reduced, delayed, or incompetent incubation by the male and thus higher embryo mortality.

4) Greater population structuring leads to more inbreeding, a higher incidence of lethal recessives exposed during embryo development, and thus higher embryo mortality.

No doubt other plausible hypotheses could be proposed. Two other variables found to have a significant effect on hatchability were nest type and diet. The reasons for this are again largely speculative. In the case of nest type, one possibility is that the lower hatchability found in hole-nesting species is an indirect result of a correlation between hatchability, predation, and inexperienced breeders. If inexperienced birds are more likely both to have their nests depredated and to have lower hatchability (see below), then species whose nests are preyed upon less frequently (such as whole nesters) would indirectly appear to have lower hatchability, simply because for ever nestsof inexperienced birds would get destroyed. This possibility could be tested by carefully analyzing the relationship between hatchability and predation rates.

Diet was examined primarily in order to assess the possibility that environmental contaminants reduce hatchability in species higher in the food chain. Although this
hypothesis was supported by the relatively high hatchability in herbivorous and granivorous species, there was no difference between species considered to be primary carnivores and those that are secondary carnivores, where the greatest effect of contaminants would be expected to occur. The increased hatchability in species depending on plant rather than animal food is perhaps an indirect result of lower nest attentiveness in insectivores due to the longer time they may require for foraging (Skutch 1976). Alternatively, the effect of diet could be an artefact of synchronous compared to asynchronous hatching, given the assumptions that carnivorous species are more likely to hatch their eggs asynchronously and that hatchability is likely to be lower if birds must begin foraging for food before the hatching of all eggs in a clutch. Additional hypotheses can certainly be envisioned. In addition to the factors considered above, at least six other variables have been proposed to influence hatchability in wild populations of birds.

1) Season: Hatchability has been found to decrease in second broods and/or late in the season in Eastern Bluebirds and to increase late in the season in Dickcissels.

2) Age of parents: Hatchability is higher in nests of older, presumably more experienced individuals in Snow Geese and in the European Blackbird.

3) Clutch size: Hatchability varied with clutch size, being highest in intermediate sized clutches, in a population of Western Gulls.

4) Population density: Birds living at low densities (for instance, at the periphery of their range) should have lower hatchability due to greater difficulty of synchronizing reproduction between the sexes. To my knowledge, the only author subsequently invoking this hypotheses Shields to explain the apparently low hatchability he observed in Savannah Sparrows.

5) Reproductive synchrony: Synchrony between the sexes is important in gamete production and for appropriate behavioural responses. The former is not likely to be of significance to hatchability, however, because the relatively low cost of sperm production makes it likely that males will be fecund at all times of potential female receptivity.

6) Life-history strategy: At least two papers have proposed that low hatchability is an adaptation to reduce brood size in the face of selection for lowered fecundity. This hypothesis seems unlikely, primarily because of the energetic waste incurred by females adopting such a strategy compared to the alternative of simply laying fewer eggs. Of course, the magnitude of the energetic loss, and thus the strength of selection against laying infertile eggs, would depend on egg size and foraging conditions during the egg-laying period and could vary considerably among species.
**Egg nutrition for health promotion**

Egg Nutrition for Health Promotion, highlighted the fact that the hen’s egg is, indeed, an amazing natural product and that there are many marketing opportunities for the hen’s egg, in addition to selling it as shell egg and raw egg product. However, some of the presenters highlighted the economic realities associated with the production and sale of the wide range of egg chemicals and this will be discussed further.

There are many marketing opportunities for eggs in forms other than shell egg and unmodified egg product. Eggs can be enriched with substances beneficial to human health such as selenium, zinc, vitamin E, folate, lutein, choline, phytoestrogens and omega-3 long chain fatty acids. Substances that inhibit the growth of microorganisms can be extracted from egg white and eggshell membranes. Eggs can be used for antibody farming and such antibodies can be used to treat lung infections in people with cystic fibrosis, dental caries, the organism that causes stomach ulcers and the organism responsible for diarrhoea in children in developing countries. Products from eggs are also used in the cosmetics industry. The challenges for the wider industry are to ensure that these ‘ovo-nutraceuticals’ and ‘bio-medical products’ can be produced cost-effectively, to increase the range of products available on the market, to increase market penetration and be competitive against rival products.

**Processing technologies for ovo-nutraceuticals and bio-medical products**

Hen’s egg is highly nutritious food containing high quality protein, twice as much unsaturated fat as saturated fat and an excellent source of minerals including iron and phosphorus and all the vitamins except vitamin C. The egg consumption has increased and about 30% of consumption is egg products such as liquid egg white, liquid egg yolk, liquid whole egg, extended shelf-life whole egg, frozen egg white, salted egg yolk, sugared egg yolk, salted whole egg, sugared whole egg, dehydrated egg products, and manufactured egg products.

It is possible to influence the composition of the egg in terms of levels of selenium, zinc, vitamin E, folate, lutein and omega-3 fatty acids. Lutein and zeaxanthin, which reduce the incidence of macular degeneration of the eye, are easily transferred through the diet of the hen into the egg where they have a high bioavailability. **Choline**, which is important during pregnancy and may assist with dementia such as Alzheimer’s Disease, is found in other foods (beef liver, beef steak, cauliflower) but has a better bioavailability in the egg. **Lysozyme** is easily separated from egg albumen and can be modified in various ways. Lysozyme is used to prevent gas formation in cheese, increase the shelf life of meat products, enhance foaming of wines, as a food sweetener, in cold remedies and mouth washes. Shell
membranes also contain enzymes that lyses gram positive bacteria (lysozyme), gram negative bacteria (β-N-acetylglucosamidase) and shell membrane extracts have been shown to inhibit Listeria, Escherichia coli, Salmonella, and Staphylococcus aureus. **Proteins** from the organic matrix of the eggshell have been shown to inhibit Pseudomonas, Bacillus and Staphylococcus and pancreatin-treated water-soluble yolk protein has been shown to inhibit Streptococcus mutans. **Avidin** from eggs binds biotin and can be used as a pesticide. Transgenic maize containing avidin resists post- and pre-harvest pests and has been found safe when fed to mice. Biopolymer edible films and coatings made from egg white proteins are used to encapsulate foods and cosmetics, as carriers of antioxidants and flavours in the food, chemical and pharmaceutical industries. The main challenges in relation to products from eggs are the difficulty of extracting some proteins economically and the problem of allergies.

Many challenges are facing the egg industry in the development and marketing of ovo-nutraceuticals and bio-medical products. **The composition of the egg is altered by regulating the hens’ dietary intake or immune system and extracting egg components.** These products are not produced by genetic modification. The proportion of eggs consumed, as product, is currently 30% but is expected to reach 40% in the U.S. It was pointed out that there is currently a limited range of offerings of ovo-nutraceuticals and biomedical products and that market penetration is relatively small. Challenges facing the expansion of these markets include costs of production, scale of operation, regulatory issues, consumer awareness and receptivity, the competitive environment and the finding of outlets for the residual egg components that remain following the extraction of the target compound. Unless such outlets are available, the enterprise is not cost-effective. **For shell eggs such as enriched eggs and egg product** such as dried eggs, the proprietary position is that there are patents of limited scope, the know-how to produce them exists and there are relatively low competitive barriers. For extracted egg components, there are higher capital investment requirements, higher barriers to entry and higher risks.

Advances in the extraction of various components such as immunoglobulin, lipids, phospholipids and yolk proteins from egg yolk components, egg yolk is diluted and then subjected to freeze-thaw cycling. Various methods (ultrafiltration, precipitation with ammonium sulphate) are used to concentrate the product. Factors such as temperature, pH and salt all influence the process.

**Methods of reducing the cholesterol content of shell eggs** between 15% and 30% of individuals exhibit a hyper-response to dietary cholesterol. In order to manipulate cholesterol levels, different parts of the cholesterol biosynthetic pathway may be
targeted. Established approaches include genetic selection (this appears to be effective only in increasing cholesterol levels), alteration of the hen’s diet, hormones, non-pharmaceutical biochemicals, and pharmacological agents. The use of various nutrients, non-nutritive factors or pharmacological agents have, at best, reduced egg cholesterol by 10% whereas oral administration of statins, garlic paste or pharmacological amounts of copper reduced egg cholesterol by 46%, 32% and 34% respectively. The opinion that further reductions in egg cholesterol levels will be achieved by manipulation of key genes associated with the uptake and synthesis of lipids.

Nutritional enhancement of shell eggs

The importance of adding antioxidants such as selenium, vitamin E and lutein to the diets of hens in order to increase the levels of these substances in the egg. These antioxidants have potential benefits in themselves and may also be used to reduce lipid per-oxidation in omega-3 enriched eggs, thus reducing the fishy taste. The advantages of using organic selenium, as opposed to inorganic selenium, in the diets of hens to increase the selenium content of eggs. The health benefits accruing from xanthophylls in eggs were outlined. The xanthophyll carotenoids, lutein and zeaxanthin, etc. have been used in the poultry industry for many years as cosmetic colouring agents for egg yolks and broilers, often in combination with red carotenoids.

In humans, lutein and zeaxanthin accumulate in the lens of the eye and also the macular region of the retina, helping to maintain normal visual function and protecting against macular degeneration and cataracts. There is also some evidence that lutein is protective against cardiovascular disease and some cancers (breast, colon). Eggs can provide lutein in a form that is highly bioavailable and the lutein content of eggs can be modified by manipulation of the diets of the hens.

The relatively low transfer efficiency of lutein from diet to hen’s egg and its possible mechanisms for increasing this transfer efficiency may be considered. Lutein is found in spinach, broccoli, alfalfa, corn-gluten and marigold meal. Lutein absorption is related to fat utilization and digesta viscosity.

The difference between a nutrient and a nutricine are discussed here. Nutricines include organic acids and antioxidants that are used to maintain feed quality and hygiene, flavours used to increase feed intake, enzymes used to increase digestion and absorption, organic acids and oligosaccharides that modulate the function of the gastrointestinal tract, carotenoids, glucans and herbal extracts that modulate the immune system and antioxidants that reduce oxidative stress and reduce the incidence of some non-infectious diseases.
Carotenoid and lutein are previously used as a cosmetic colouring agent in eggs and broilers; they are now considered an important **nutricine** in poultry and human health. **Lutein absorbs free radicals so helps protect against oxidative damage and supports the immune system.** Lutein is a naturally occurring carotenoid, which usually occurs with zeaxanthin and occurs in all green leaves, whereas barley, rice, sorghum, wheat and oilseed meals are low in lutein. The benefits of lutein in protecting the chick during hatching and presented data indicating that lutein can improve immune function in dogs and avian species.

The eggs can be enriched with folate and that the form of folate found in eggs is more available than crystalline folic acid. Excess crystalline folic acid can risk masking the symptoms of pernicious anaemia (vitamin B12 deficiency), whereas the folate in eggs does not cause this problem. Dietary folate is known to be important in the human diet for normal cell division, synthesis of red blood cells and metabolism of proteins and amino acids. It is also important in reducing the incidence of neural tube defects (e.g. spina bifida) and miscarriages. There is also some evidence that folate reduces the incidence of cardiovascular disease as it is a cofactor in the metabolism of homocysteine and elevated levels of homocysteine are an independent risk factor for cardiovascular disease. As Alzheimer’s disease and dementia are linked to cerebrovascular disease, folate may have a role in reducing the incidence of these diseases also.

Many nutriceuticals currently targeted at older women contain soy isoflavones (phytoestrogens). The eggs of Japanese quail can be enriched with the soy isoflavone genistein which has a structure similar to the female hormone, oestradiol.

**Egg lipids**

The process of feeding **conjugated linoleic acid (CLA)** to chickens in order to produce **CLA-enriched eggs.** CLA is a natural trans-fat that is produced in the rumen of ruminant animals so is therefore found mainly in dairy and beef products. The interest in CLA isomers arises from evidence that they possess anti-carcinogenic properties and can modulate the immune system. They have also been shown to improve feed efficiency and decrease body fat deposition in pigs and broiler chickens. Evidence suggests that more than 3 grams per day needs to be consumed by humans in order to accrue health benefits. Because CLA is found in fat, reduced consumption of fat in dairy and beef products means that less CLA is consumed from these sources. The incorporation of CLA into eggs is an easy and efficient way to increase CLA intake. Addition of CLA to the diets of hens changes yolk shape by making the yolk more round but there is no effect on egg weight, Haugh units or the
nutritional value of the eggs. CLA ingestion was found to increase the deposition of lipid droplets in the livers of laying hens but not broilers. When CLA enriched eggs were stored under refrigeration for 40 days, the water content of the yolk increased. Long term storage (3-4 months) resulted in a reddish colour in the yolk.

The research study explained the evidence that human diets in earlier times had a ratio of omega-6 to omega-3 essential fatty acids of approximately 1 whereas most present day Western diets have a ratio of from 15 (U.K.) to 16.7 (U.S.A), as compared to Japan where the ratio is 4. This means that the current Western diets contain excessive amounts of omega-6 fatty acids and are deficient in omega-3 fatty acids. This imbalance is thought to contribute to diseases such as cardiovascular disease, cancer, and inflammatory and autoimmune diseases. One way of increasing the consumption of omega-3 fatty acids is via enriched eggs.

Omega-3 fatty acids have been shown to be beneficial in the human diet in terms of affecting plasma lipid levels, visual function and child growth and development. The benefits of the omega-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) from fish oils and alpha-linolenic acid (ALA) from plant oils in reducing plasma triglyceride levels in humans. High triglyceride levels are a risk factor for cardiovascular disease and stroke. However, these compounds appear to have little effect on low-density lipoprotein (LDL) cholesterol, another risk factor. There is potential for an improved effect on plasma lipids if EPA and DHA are conjugated to plant sterols as a study conducted with guinea pigs showed that both triglycerides and LDL cholesterol were reduced by such a combination.

The importance of dietary omega-3 fatty acids in visual function was discussed here. The long chain polyunsaturated fatty acids (LC-PUFA, C20:4n-6 and C22:6n-3) are essential for normal visual development in infants. These fatty acids are found in mothers’ milk and it has been recommended that they may be added to infant formula. There is also evidence that LC-PUFA have a role to play in reducing the incidence of degenerative diseases of the retina of the eye such as retinitis pigmentosa and macula dystrophy.

More general aspects of the importance of omega-3 polyunsaturated fatty acids (DHA and arachidonic acid, AA) in child development, there is now a tendency to use iron-fortified cereal as the first semi-solid food for infants whereas, traditionally, eggs and brains were fed. Egg allergies affect approximately 3% of infants under three years of age. The benefits of supplementation of diets with DHA and AA in improving mental and psychomotor development and development of the immune system in children and saw the main role of eggs as being during the weaning period. To incorporate the omega-3 fatty acids, they just want a small volume of AA and DHA to add to existing formula. Enriched eggs remain a
potentially important source of the omega-3 fatty acids in the diets of infants, children and adults.

**Antibodies from eggs**

Hens are able to deposit antibodies into the yolk of the egg for the purpose of protecting the developing chick. These yolk antibodies are collectively referred to as IgY, which stands for immunoglobins from yolk. Antibody-farming technology exploits this capability of the hen to produce a range of different types of antibodies in the eggs by immunizing the hen with specific substances and is an easy and inexpensive process. Hens are immunized several times and then require booster doses every 2-3 months. The antibodies, which are stable for several months, act by preventing adhesion of microbes to epithelial cells, inhibiting the growth of microbes and neutralizing the toxins produced by microbes.

The production of yolk antibodies for oral treatment of cystic fibrosis patients against *Pseudomonas aeruginosa* infections in their lungs because the life expectancy of cystic fibrosis patients is 40-50 years and the main killer of these patients is *Pseudomonas aeruginosa*. This organism is impossible to eradicate but treatment with the yolk antibodies prolongs the time between active infections, reduces the need for antibiotics, postpones the onset of chronic infections and helps to preserve lung function. The formulation of the yolk antibodies has now been changed to contain 6 strains. The need for a double blind study to determine the effectiveness of the product and the fact that it requires orphan drug status (that is, it has a limited market).

Production of new product for treatment of people suffered from coeliac disease, because this disease can be controlled by a gluten-free diet, which was first introduced in 1950. The symptoms of the disease are chronic diarrhoea, weight loss, anaemia, bone pain, behavioural changes, gastrointestinal disease and delayed growth. There is a genetic basis to the disease which interacts with environmental factors. The new product (NutraGuardTM) contains specific IgY along with vitamin E, DHA, folic acid and selenium and can be administered as capsules or added to foods.

The ongoing work that is attempting to develop IgY anti-prion antibodies for use in assays to detect the presence of prion diseases such as bovine spongiform encephalopathy’s (BSE-assisys). Prions are proteinaceous infectious particles consisting of 151-190 amino acids. It has proved difficult to produce specific antibodies in mammals because of the similarity of the amino acid sequences to those found in other mammalian proteins. However, the use of a different class of animals, the birds, has resulted in some breakthroughs.
Antibodies from egg yolk can even be used to treat dental caries, *Streptococcus mutans* is the main cause of dental caries and infection of humans does not occur until the final primary tooth eruption. Once a person is infected, they are always infected. Immunisation of hens with *S. mutans* glucan binding protein B results in the appearance of antibodies in egg yolk that have been shown to protect against dental caries in a rat model. The best time for this product to be applied would be at the time of initial *Streptococcus mutans* colonization and after mechanical/chemical cleaning of teeth.

The organism *Helicobacter pylori* causes gastric ulcers in humans. *Helicobacter pylori* specific IgY prepared from the yolk of hens immunized with has been shown to be effective in treating *Helicobacter pylori* infections. Apparently, approximately half the world’s population is infected with *H. pylori*, with the incidence being higher in developing countries (80-90%) than in developed countries (10-50%). The antibodies, which are usually given in combination with antibiotics, appear to work by inhibiting the adhesion of the bacteria to the epithelial cells of the stomach.

Ongoing work that is investigating the use of egg yolk antibodies for the treatment of human rotavirus, which is responsible for causing diarrhoea in children and is a major problem in developing countries. The same principle of “designer” antibody production can be achieved in bovine milk, following immunization of the cow.

**Process of development of designer Egg**

The concept is the return of alpha-linolenic acid (ALA, C18:33), described as “wild fatty acid” to the rations of land-based bred animals so that their fatty acid ratios ($\omega_6$: $\omega_3$) returned to 1:1, the ratio characteristic of fat deposits in wild animals and such a change would have health benefits for these animals and the humans who consume them.

The uses for sialic acid which is described as the “sugar” in egg, is found in all parts of the egg: yolk, white, chalazae, yolk membrane, egg shell, in order of diminishing content. Sialic acid has been shown to inhibit rotavirus. The use of eggshell calcium has marketing potential as the calcium contained in it is highly bioavailable and it doesn’t give a chalky taste. Products utilizing eggshell calcium are already on the market. The eggshell membrane can be used to treat wounds as it promotes collagen synthesis, absorbs moisture, releases proteins and has antimicrobial activity. Yolk protein contains all the essential amino acids required by 2-5 year old children. Lysozyme obtained mainly from egg white is able to lyse gram-positive bacteria (but not gram negative ones). Yolk lecithin is a safe and natural source of AA, DHA, cholesterol and choline as an additive for infant formula.

**Importance of egg lecithins**
Sales of egg lecithin have increased in recent years by 340% worldwide, 475% Far East, 320% Europe and 245% U.S.A. Of the lecithin sold, 60% is used in infant formula, 15% in injection solutions for clinical nutrition, 15% in cosmetics and 10% as functional foods. The composition of egg lecithin (the fatty acid profile) can be optimized by pure vegetable feeding of hens and use of different production technologies. Infants are not able to synthesise AA and DHA from fatty acid precursors so they need to obtain these either from mothers’ milk or infant formula. There is competition from other fatty acid sources for inclusion in infant formula. Egg lecithin is used for total parenteral nutrition and injections because of its emulsifying properties. In cosmetics, it emulsifies and stabilizes, acts as a skin nutrient and moisture regulator of skin, protects skin and hair and acts as a carrier for pigments and liposomes. Egg lecithin has a range of applications in food products.

The designer food concept is currently very strong. The period of 1920-1950 considered as the vitamin era, 1970-1990 as the mega-vitamin era and 1990 to the present day as the functional food era. **Functional food defined as foods that encompass potentially healthful products including any modified food or food ingredient that imparts benefit beyond the food that they contain.**

The egg of the hen is a natural product which, by virtue of its role in nature has many properties that can be exploited by humans. It can be used as a means of delivering substances beneficial to human health in a form that is natural and highly bio-available. The hen’s egg can be used for the extraction of its component parts and it can be used for the production of antibodies to a wide range of agents. However, the commercial realities of the production of this range of products are an important determinant of the extent of the market for the ovo-nutraceuticals and bio-medical products from eggs.

**Designer egg production through nutrient manipulation**

**Designer food:**

Designer foods are also termed as functional, fortified, enriched or nutraceutical value added foods. Designer foods have better potential effects on health besides providing the basic nutritional benefits.

**Designer eggs:**

The designer eggs are produced by nutritional manipulation of poultry diets i.e. addition of different health promoting components like antioxidants, minerals, omega fatty acids, vitamins, and various non-nutrient feed additives. The altered fatty acid profiles specifically the enrichment of egg and meat with omega 3 fatty acids, lowering of cholesterol
and other compositional components such as choline, conjugated linoleic acid, lutein, selenium, and vitamins B, D, E and K, were produced recently.

Day by day increasing demand from the domestic consumers for designer organic food products like eggs, meat and milk. The poultry eggs and meat are nutrient rich food and now regarded as an inexpensive, convenient and low calorie source of high quality protein with several other essential nutrients. However, the health conscious consumers demand for the wholesome, healthy and nutritious food products free from harmful residues. They are more interested and ready to pay for the products which are more beneficial, wholesome and health promoting in order to improve their well being.

The poultry products like egg and meat have already gained a healthy image, so in order to curb the prevalence of chronic diseases and several attempts were made to modify the eggs and meat by adding ingredients which are beneficial for the health or by eliminating or reducing components that are harmful.

This modification resulted in development of functional egg and meat. Improving consumers’ health and nutritional status by designing nutritional profile of poultry egg and meat through dietary approaches is relatively simple and economic. Nutritional diets of birds influence meat qualities in terms of nutritive value, acceptability, human health and processing. Eggs can be designed through dietary approaches either through supplementation of specific nutrients, or certain herbs or specific drugs that have functional and therapeutic properties. In case of poultry, there are two types of value addition of products:

· Pre-slaughter or pre-oviposition value addition i.e. value addition before the product is produced. Products like designer / organic / functional eggs and meat will come under this category which are usually free from residues of pesticides, drugs and other harmful chemicals.

· Post-slaughter or post-oviposition value addition i.e. value addition after the product is produced.

These types of value addition can be done mostly by combination of managerial and nutritional manipulations.

**Designer Eggs**

Designer eggs are those specially produced eggs which are rich in additional nutrients and health promoting components like carotenoids, chelated minerals, EPA and DHA like omega 3 fatty acids, selenium, vitamin E and other immune-modulating factors. Designer eggs contain 600 mg of omega-3 fatty acids, equivalent to a 100 g serving of fish. Omega-3 fatty acids help in lowering dietary cholesterol content in the diet. Vitamin E, a fat soluble
vitamin as well as an effective antioxidant, is enhanced to 100 per cent in these eggs. These eggs prevent cancer causing factors, cardiovascular diseases (CVD), and improve immunity and overall health status.

Studies have shown that when 2-3 designer eggs are consumed every day, 100 per cent of the daily requirement of essential fatty acids is met. High-density lipoprotein (HDL) levels are raised while low-density lipoprotein (LDL) levels are decreased, blood fats are reduced, and more than 60 per cent of the daily vitamin E requirement is fulfilled. That’s why designer eggs are sold at a premium price and have a better consumer preference than the regular eggs.

In the late 80s, some workers produce nutrient enriched eggs and developed designer egg, rich in n-3 fatty acids with antioxidants and patented as Designer Egg. Later in 1997, developed eggs enriched with conjugated linoleic acid (CLA). In Australia, the enriched eggs with folic acid and iron were produced. Other available designer eggs in the market include eggs enriched with vitamins. In Canada, produced lutein and selenium enriched eggs which help in preventing eye disorders. In India, Narahari has also developed Herbal Enriched Designer Eggs (HEDE), which is not only rich in carotenoids, n-3 PUFA, selenium, trace minerals and vitamin E, but also rich in herbal active principles like Allicin, Betaine, Euginol, Lumichrome, Lumiflavin, Lutein, Sulforaphane, Taurine and many other active principles of herbs, supplemented in the diets of hens. These eggs also contain natural sterols (phytosterols) like β-sitosterol, Brassicasterol, Campesterol, Stigmasterol etc. which are cardiac friendly in nature. The nutrient contents of designer eggs are comparatively higher than ordinary eggs as shown in Table 1.
The incorporation of ω-3 PUFA into eggs has been used by scientists to alter ω-6:ω-3 ratio towards the desired dietary ratio. Fatty acid composition of regular eggs and ω-3 PUFA enriched eggs are presented in Table 2. As an important part of the diet, the omega 6 to omega 3 ratios in the chicken egg has increased dramatically, from 1.3 under absolutely natural conditions to 19.4 under a standard United States Department of Agriculture (USDA) diet. Since the ratio between omega-6 and omega-3 in eggs can easily be manipulated through diet enrichment, development of omega-3-enriched eggs can contribute to an improved balance between omega-6 and omega-3 in the human diet.

Sources of ω-3 PUFA such as fish oils, fish meal, marine algae or a combination of several of the above can be used as supplements in layer diets. However, supplementation with fishmeal or fish oil can exert a negative influence on the sensory properties of the egg.

**ω-3 (Omega-3 Fatty Acids) enrichment**

The omega-3 fatty acids, also called as n-3 fatty acids are a family of polyunsaturated fatty acids which have the first C-C double bond at the third carbon position counting from the omega end of the carbon chain. Important omega-3 fatty acids are derived largely as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) from fish oils and as α-
linolenic acid (LNA) from plant oil. Omega-3 fatty acids are usually obtained from two sources which can be classified as:

The marine type ω-3 PUFA, DHA and EPA which are more commonly found in deep sea cold water fish (such as salmon, mackerel, herring, tuna, bluefish and anchovies), fish oil and marine algae. Marine algae are an efficient dietary alternative to other n-3 fatty acid sources. Some marine microorganisms synthesize significant amounts of long-chain fatty acids, particularly DHA and EPA. A *Schizochytrium* sp. has been used commercially as an alternative source of omega-3 fatty acids. Comparatively, PUFA of marine algal origin are more stable and active in form than that of terrestrial plant origin. It was also found that the presence of marine algae carotenoids may enhance the oxidative stability of n-3 fatty acid enriched eggs.

The terrestrial type ω-3 PUFA, LNA found in canola oil, soybean oil, flaxseed, walnuts, and spinach and mustard greens. As omega-3 fatty acid dietary sources, flaxseed oil is widely used in poultry egg and meat enrichment, due to its high content of LNA (50 to 60%) but flaxseed reduces the availability of minerals and also inhibits the activity of proteolytic enzymes.

The n-3 fatty acids have protective role against coronary heart disease (CHD). Dietary recommendations have been made for ω-3 fatty acids, including LNA, EPA and DHA to achieve nutrient adequacy and to prevent and treat cardiovascular disease. The ω-3 fatty acid recommendation to achieve nutritional adequacy is 0.6–1.2% of energy for LNA; up to 10% of this can be provided by EPA or DHA. A dietary level of 500 mg/d of EPA and DHA is recommended for cardiovascular disease risk reduction and for treatment of existing CVD, 1 g/d is recommended and these recommendations have been followed by many health agencies worldwide. Omega-3 (ω-3) eggs are the first product produced by manipulation of egg composition, and enrichment with choline, conjugated linoleic acid, lutein, selenium, vitamins B, D, E and K, and has also attracted substantial attention in relation to egg and meat quality.

<table>
<thead>
<tr>
<th>Table 2: Fatty acid composition of regular eggs and ω-3 PUFA enriched eggs</th>
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<td><strong>Egg types</strong></td>
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<tr>
<td>Regular</td>
</tr>
<tr>
<td>Designer</td>
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<td><em>(Narahari, 2005)</em></td>
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In designer eggs the n-6: n-3 PUFA ratio is decreased to about 1.5, from as much as 20 in regular eggs. This favourable change in designer eggs, will supply about 50% of the
daily requirement of n-3 PUFA to the consumers, without any change in the sensory quality of the egg. This n-3 PUFA in egg yolk has decreased the serum triglycerides and increased the serum HDL-Cholesterol levels in human volunteers, when consumed for a period of two months at two eggs per day. Since the n-3 PUFA will undergo rancidity quickly, it is essential to prevent the rancidity of the designer egg yolk lipids, by incorporating anti-oxidants in the hens' diet.

**CLA enrichment**

Conjugated linoleic acid (CLA) is a group of positional and geometrical isomers of 18-carbon unsaturated fatty acids with two conjugated double bonds (unlike linoleic acid, which has a non-conjugated diene). The most commonly occurring CLA isomers in synthetic mixtures are cis-9, trans-11-CLA and trans-10, cis-12-CLA, with minor amounts of trans-8, cis-10-CLA and cis-11, trans-13-CLA, which are indicative of more severe heating conditions during the synthesis of CLA from linoleic acid. CLAs have been shown to have anticarcinogenic, antiadipogenic, antidiabetic and anti-inflammatory properties. Several studies have shown that concentrations of CLA in yolk lipids increased linearly as dietary CLA increased. Eggs produced by hens when fed with 5.0% CLA will contain 310 to 1000 mg of CLA per egg which could provide a substantial amount of CLA in human foods to meet the proposed CLA requirement. Despite all the beneficial effects of CLA enrichment, it affects the texture and juiciness of the meat by making it tough and dark.

**Vitamin E enrichment in Eggs**

As ω-3 fatty acid enriched eggs are more susceptible to lipid oxidation, supplementation with vitamin E is generally recommended to stabilize egg lipids against rancidity and extend the shelf life of the product. Supplementation of dietary vitamin E does not have a significant effect on daily feed intake, feed efficiency, egg weight and laying rate. Supplementation of vitamin E in layer diets enhances egg production and increase antioxidant properties of egg yolks and plasma of White Leghorn hens during heat stress. There is an improved feed intake, egg production, vitelline membrane strength (VMS), albumen and yolk height and foam stability in heat stressed hens when fed with vitamin E supplemented diet (60 IU vitamin E/kg feed). Dietary vitamin E improved laying hen performance significantly in a cold environment, including feed conversion rate, body weight and egg production. A decline in egg yolk flavour and overall egg acceptability was reported when a higher level of vitamin E (100 ppm vs. 10 ppm) was used along with 20% dietary flaxseed. The recommended level of dietary vitamin E in feed should be 100 IU/kg in commercial n-3 fatty acid egg production.
**Selenium enrichment in Eggs**

Selenium (Se) is a necessary trace mineral in reducing the oxidative damage of cell membranes of animals and humans. The Se is an essential part of a variety of seleno-proteins, such as glutathione peroxidises (GSH-Px), and at least six forms of GSH-Px were reported; GSH-Px is involved in cellular antioxidant protection. Inorganic sources (selenate and selenite) and organic sources of selenium supplements (selenium yeast) are used in typical corn-soybean meal based layer diets to develop the Se enriched egg. Organic Se supplementation provides longer duration of freshness qualities of eggs and it is used widely because its absorption is higher than that of the inorganic form. Inorganic Se has lower transfer efficiency to eggs than the organic Se. Supplementation of organic Se to layer diets significantly improved egg production, egg weight, feed conversion ratio, albumen height, and specific gravity.

The use of Sel-PlexTM, organic Se in the layer diet at 0.3 mg/kg resulted in significantly higher albumen values (Haugh Units) after seven days of storage. The Se has a sparing effect on vitamin E, such that selenium supplementation can increase the vitamin E content of egg yolk. Sodium selenite and selenocysteine result in greater concentrations in the yolk. Selenomethionine results in greater deposition in the albumen. However, a high level of Se is toxic. The body weight, egg production, egg weight and feed conversion ratio decreased significantly at increased Se concentrations when chickens are fed at 0, 5 and 10 ppm Se in the basal diet. The maximum allowable level (0.3 ppm) used in commercial poultry diets is well below toxic levels.

**Roles of antioxidants in eggs**

Poultry eggs are rich sources of natural antioxidants like vitamin-E, Se, carotenoid pigments, flavinoid compounds, lecithin and phosvitin but at the same time, are highly susceptible to oxidative rancidity during storage. These antioxidants will protect the fat-soluble vitamins and other yolk lipids from oxidative rancidity. The designer eggs and meat, not only contain high levels of the above anti-oxidants but also contain synthetic anti-oxidant like Ethoxyquin and anti-oxidants of herbal origin such as Carnosine, Curcumin, Lycopene, Quercetin and Sulforaphene, depending upon the herbs used in the poultry diet. Hence, supplementation of these antioxidants in the diet is essential to maintain the shelf life of the product.

Along with antioxidants like Vitamin E and Se, the enzymes like glutathione peroxidase, superoxide dismutase, catalase constitute an integral part of antioxidant cellular enzyme system in omega-3 enriched products to reduce lipid peroxidation. The dietary
supplementation of vitamin E is commonly used in commercial n-3 enriched products to mitigate the oxidation of n-3 FA, thereby preventing the formation of undesirable fishy flavor and warmed over flavor in refrigerated cooked and raw meat. Besides these, other antioxidants as chemicals and herbs may be added, to prevent oxidative rancidity.

**Advantages of antioxidant enrichment of poultry eggs**

- Reduce susceptibility to lipid per-oxidation and rancidity.
- Prevent ‘fishy taint’ of the product.
- These could be a good source of antioxidants in human diet.
- Prevent destruction of fat-soluble vitamins and natural fat-soluble pigments.

**Reduction in cholesterol content**

A large egg contains about 213 mg of cholesterol per yolk and chicken meat contains about 60 mg per 100 g. Yolk cholesterol content in omega-3-enriched eggs obtained from laying hens fed with 10% menhaden fish had 13.6% less yolk cholesterol than did the control eggs. Similarly, birds fed with 1.5% menhaden fish oil or 5% whole or ground flaxseed-based diet, resulting in about a 9% yolk cholesterol reduction. Egg cholesterol levels are very difficult to influence by dietary manipulation, but some improvement has been reported from supplementing with copper and chromium. Several studies have indicated that supplementation with dietary micro-minerals (copper, chromium, zinc, vanadium, and iodine) and/or dietary vitamins (vitamin A, ascorbic acid, and niacin) may change the yolk cholesterol level.

Enzymes have been reported to increase the percentage of egg albumen. Supplementation of natural products like garlic, probiolac and *Lactobacillus acidophilus* in poultry feed help to reduce egg yolk cholesterol. It was reported that egg and plasma cholesterol levels were reduced by 23 and 22% respectively, through feeding dietary garlic powder. The effect of cholesterol metabolism by feeding plant sterols (phytosterols) to hens and reported a decrease of 16 to 33% cholesterol concentration in either plasma or egg yolk by feeding 2% dietary soy sterols with either saturated or unsaturated oil, with or without cholesterol. Feeding dehydrated alfalfa free of choice also produce lean chicken breast meat as alfalfa is a good source of saponins which is hypocholesterolaemic in nature. A reduction of serum cholesterol has been reported in broilers fed with *Lactobacillus* culture.

Dietary supplementation of amino acids like glycine, lysine, methionine and tryptophan can decrease body fat deposition. The carcass and yolk cholesterol levels can be significantly reduced by supplementing herbal plants and products like basil (tulsi), bay leaves, citrus pulp (nirangenin), garlic, grape seed pulp guar gum, roselle seeds, spirulina,
tomato pomace (lycopene), and many more herbs in chicken diets will reduce the chicken and yolk fat cholesterol levels by 10-25%.

Canola oil, linseed oil, soybean oil and sunflower oil, reduced fat and cholesterol content in cockerel thigh and breast meat. Moreover, these substances act synergistically in reducing the cholesterol levels. Hence a combination of these supplements will be more beneficial, rather than a single substance.

Poultry eggs are a good source of essential nutrients. The development of nutrient enriched value added poultry eggs greatly increased the context of functional foods for human health. Hence, by manipulating the diet of chicken with the different available feed supplements in requisite amounts, value added and health promoting chicken egg, and their products, free from drugs, pesticide residues and other harmful toxic additives can be made available to the health conscious consumers. The designing must take into consideration the production facilities, available materials, technical know-how, economic resources of the producers and environmental impacts with welfare issues.