THE EGG: NATURE'S UNIQUE MIRACLE FOOD RECENT DEVELOPMENTS AND FUTURE POSSIBILITIES

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INTRODUCTION

Prior to the 1960's, producing and maintaining quality of the albumen, yolk and shell were the major issues faced by the egg industry. In the years that have ensued, numerous changes have occurred. The most important issue was the cholesterol in egg yolk that led to the suspicion that it is the major culprit increasing the risk of coronary heart disease (CHD) and changed the attitude towards egg consumption. Consequently, egg consumption was reduced from unlimited to three eggs per week, then increased to four eggs per week followed by 'egg a day' and no limits again, provided they are consumed as part of a healthy diet that is not high in saturated fatty acids (SFA). In recent years, the cholesterol story has become a sort of myth and it remains an issue only for a specific vulnerable group. Emerging evidence suggests that eating eggs is associated with better diet quality, enhanced nutrition and several health benefits. Consequently, terminologies to describe eggs are changing from 'forbidden', 'bad for your heart' to functional, incredible, nutraceutical, pharmaceutical, super, golden, etc. However, the word miracle seems to supersede all and hence the choice of this title for this review. Every component of the egg has some function related to human or animal nutrition and adds diverse functionality to many food products, and the outlook for eggs is brighter than ever before.

Currently the eggs are viewed with interest for its biologically active components which are naturally present for the own defence of the developing embryo. These components are unique and have new and novel food and non-food applications. These are also components that can improve the general health and well-being of human and animals, and would be the main focus of this overview.

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NUTRIENT COMPOSITION OF AN EGG

The avian egg is made of shell, albumen and yolk (Figure 1). The biological function of these parts of the egg is to provide nutrition and protection against invading microorganisms to the developing embryo. All three parts of the egg are rich sources of nutrients and biologically active components; the egg shell/ membranes, in addition to being the first line of defence against invading microorganisms is a source of calcium, collagen and bio-active proteins; egg white, a source of bio-active proteins and the yolk, a source of bio-active lipids and proteins.

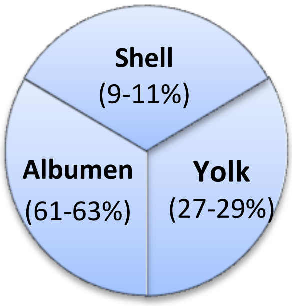

Figure 1.Major components of an egg

The major nutrient composition of the edible whole egg and its albumen and yolk are shown in Figure 2.

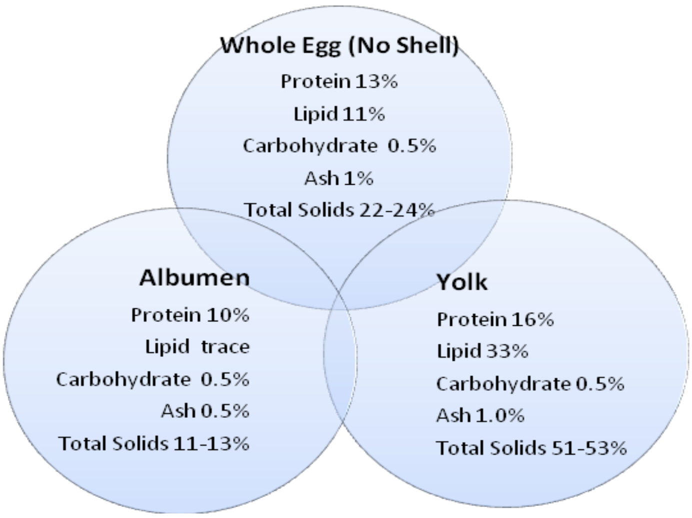

Figure 2.Composition of the major components of an egg

Eggs are a naturally nutrient-dense, easily digestible food, a valuable source of high quality protein and many essential micronutrients that paradoxically are not high in energy or saturated fats (Table 1). A medium egg is currently reported to have 66 calories (as opposed to 78 claimed earlier). Albumen is an excellent source protein with the richest mixes of essential amino acids well-balanced to commensurate the needs of humans. Composition and level of proteins in albumen (10%) cannot be changed easily as proteins are not directly transferred from the food to the egg. Formation of proteins is determined by the RNA code and takes place in the magnum. The total fat (5.8g) and SFA (1.7g) is not high and the fat is predominantly unsaturated (44% mono-; 17% polyunsaturated). They are rich in cholesterol (178mg now, as opposed to 227mg reported below). They are also packed with all vitamins, except C, most minerals and trace elements.

Table 1. Nutritional composition of raw hens' egg

Component/Nutrient	Whole Egg* Per 58g egg
Energy kj/kcal	324/78
Protein (g)	6.5
Carbohydrate (g)	Trace
Fat (g)	5.8
Saturated fatty acids (g)	1.7
Monounsaturated fatty acids (g)	2.3
Polyunsaturated fatty acids (g)	0.9
Cholesterol (mg)	225
Choline (mg)	130
Vitamins	
Retinol (µg)	98
Vitamin D (µg)	0.9
Riboflavin (mg)	0.24
Niacin (mg)	0.3
Folate (µg)	26
Vitamin B12 (µg)	1.3
Minerals	
Phosphorus (mg)	103
Sulphur (mg)	66
Iron (mg)	1.0
Zinc (mg)	0.7
Iodine (mg)	27
Selenium (µg)	6

*FSA (2002)

All these nutritional features suggest that egg is the most complete whole food in terms of diet and nutrition and its consumption can help not only the general population but also specific groups such as people with diabetes and obesity. Emerging evidence suggests that eggs due to its high protein content promote greater satiety and coupled with low calorie or reduced energy, helps in weight management.

NUTRITIONAL AND NUTRACEUTICAL BENEFITS

Shell and shell membranes

The shell along with the membranes is approximately 6g/egg and represents about 10% of the egg weight. Calcium carbonate (CaCO3) constitutes 95% of the shell, 39% of which is elemental calcium, making egg shells probably the best natural source of calcium. The remaining is an organic matrix (3.5%) made of bioactive proteins, glycoprotein and proteoglycans. Egg shell also contains useful amounts of mineral elements such as selenium, fluorine and strontium (Schaafsma et al., 2002); magnesium, boron, copper, iron, manganese, molybdenum, sulphur, silicon and zinc (Bee, 2011). The former authors also reported a positive effect of eggshell calcium supplementation on bone mineral density.

In many countries, they are dried at high temperature to decontaminate and used a source of calcium in animal feeds. Eggshell powder as a calcium supplement to laying hens during late production phase has been reported to increase egg production and improve quality of the shells (King'ori, 2011). Ground eggshells are also effective liming sources that improve soils.

Eggshells and shell membranes are non-edible by-products, but contain biologically active compounds that have multiple uses in nutrition, medicine, cosmetic, nanotechnolgy and pharmaceutical applications and have been patented (Cristianne et al., 2011). Shell membrane is made of 69% protein (10% collagen), 3% fat, 1.5% water and the remaining 27%, ash (MacNeil, 1997). Eggshell membrane collagen is reported to be bio-safe and less potent in causing autoimmune and allergic reactions (Long, et al., 2004). Ingestion of glycosaminoglycans, chondroitin and proteins from natural chicken eggshell membrane are suggested to be beneficial for healthy joints and regulation of connective tissues (Ruff et al., 2009). Hyaluronic acid is isolated from glycosaminoglycans for treating osteoarthritis and periodontal diseases. A novel potential antibacterial protein, ovocalyxin-36 (OCX-36) was recently identified from egg shell membrane, with its therapeutic applications yet to be studied (Gautron et al., 2007). However, the shape or size or thickness or solubility of the shell membrane is difficult to be modified due to the presence of disulphide bonds in its molecular structure and needs the cleavage of these bonds in order to extract the soluble eggshell membrane protein.

Polypeptides isolated from eggshell tissue are patented to have potential benefits to stimulate osteoblast cell growth, leading to possible applications in bone grafting and tissue engineering, i.e., cultivating bone cells ex vivo (Elias, 2010).

Fresh eggshell membrane is reported being utilized as an antimicrobial tissue adhesive to aid healing of certain skin lacerations. Fibres from these membranes adhere to the skin tissue strongly.

Egg white (albumen)

Egg white that makes up around 60-63% by weight of the egg is a concentrated source of the highest quality food protein (10-11%) known. It's high pH (7-9) and viscous nature slows down the migration of any bacteria towards the embryo. It is made of 40 different proteins with several more yet to be identified. It is hoped that the recent chicken genome sequence publication will help researchers to identify the remaining proteins and other minor components. Many of these proteins are present in small quantities; nevertheless possess significant bio-activity, mainly antimicrobial or even antiviral activity, as albumen serves as the second barrier for the developing embryo against invading microorganisms. However, they also perform additional functions. Table 2 shows a list of the different proteins found in the albumen.

Table 2. Bioactive **p**roteins of the albumen*

Protein	% of protein	Properties
Ovalbumin	54	Immune-modulating, antihypertensive activities
Ovotransferrin	13	Binds metal ions, antimicrobial
Ovomucoid	11	Serine proteinase inhibitor, Immune-modulating activity
Ovomucin	1.5-3.5	Antiviral, Immune-modulating, hypo-cholesterolemic activities.
Ovoglobulin		
Lysozyme (G1)	3.5	Lyses bacteria, antimicrobial, immune-modulating activities.
Ovoglobulin (G2)	1.0	
Ovoglobulin (G3)	1.0	
Cystatin	0.05	Cysteine proteinase inhibitor, antibacterial
Ovoflavoprotein	0.8	Binds vitamin B_2, antimicrobial
Ovoinhibitor	0.1	Serine proteinase inhibitor, antiviral.
Ovostatin (ovomacroglobulin)	0.5	Serine, cysteine, thiol and metallo proteinase inhibitor, antibacterial.
Avidin	0.05	Binds biotin, antimicrobial activity
Enzymes		

*Mine and Kovacs-Nolan, 2004

Of the antimicrobial proteins, lysozyme and cystatine are the most interesting and their levels and activity can be boosted by improving the immune status of the hen. Lysozyme, a bacteriolytic enzyme is currently used as a preservative in cheese making and an antimicrobial in eye drops. It is also used as a spray on vegetables to prevent bacterial growth. It is natural, relatively heat resistant and can be effective even after pasteurization. It is effective against gram positive bacteria, *Listeria monocytogenes* and *Clostridium botulinum* and other spore formers.

Most of the other egg white proteins also appear to possess antimicrobial properties. Ovotransferrin, ovoflavoprotein and avidin bind metals, riboflavin (vitamin B2) and biotin respectively and make them unavailable to the bacteria. Ovotransferrin is particularly effective against gram negative bacteria. Fronting et al. (1986) found conalbumin to be an effective antioxidant in ground turkey meat. Avidin-biotin technology is currently popular in several bio-medical applications and will not be covered here.

Egg is also a rich source of bioactive peptides. It is well established that during digestion or processing, small peptides may be released and could act as regulatory compounds that may have certain physiological benefits for human health. These bio-active peptides can either be absorbed through intestine to enter the blood circulation and exert systemic effects or can produce local effects within the gastrointestinal tract. Various bioactive peptides, such as antimicrobial, anticancer, antihypertensive or angiotensin converting enzyme (ACE) inhibitory peptides have been reported from eggs (Kovacs-Nolan, et al., 2005). ACE inhibitory peptides derived from egg proteins have the potential to significantly reduce blood pressure in both hypertensive animals and humans (Miguel, et al., 2005).

Milk protein hydrolysates are widely used in formulations for sports drinks, infant formulas and meals for the aged or elderly. Such applications are also feasible with egg protein hydrolysates, which has the added advantage that it lacks the bitter taste associated with milk protein hydrolysates (Dziuba, 1999).

Edible films from egg white proteins, which can carry antioxidants, antimicrobials have been of recent interest. These films have been studied for other applications in food and pharmaceutical industries as well.

Egg yolk

Yolk is present in the centre of an egg, account 27-29% and provide a much more concentrated source of nutrients than egg-white. It is 50% water, 30% fat, 12% protein and the remaining are micro nutrients such as vitamins, minerals, pigments, etc. It is an oil-in-water emulsion, stabilised by lecithin, commercially known to be the best emulsifier. The main lipids constitute 66% triglycerides, 28% phospholipids and 5% cholesterol. Of the phospholipids, lecithin constitutes 73%. Recent studies have found that the yolk contains 177 mgs of cholesterol, just over 10% less than the 202 micrograms previously recorded for a medium egg. The proteins of egg yolk include low-density lipoproteins, glycoprotein, phosvitin, serum albumin and immunoglobulin (IgY). The lipid-based functional ingredients constitute choline, immunoglobulin IgY, omega 3 polyunsaturated fatty acids (PUFA) and carotenoids, lutein and zeaxanthin, all exclusive to yolk (Table 3).

Table 3. Bioactive components of the yolk

Protein	% of whole egg	Function
Choline	0.4	Lipid transport, fetal brain development
Immunoglobin (IgY)	0.3	Antibodies
Phosvitin	0.8	Antioxidant (metal binding)
Omega 3 -PUFA	0.6-1%	Prevention of CHD, brain development
Carotenoids	Traces	Antioxidants
Sialyloligosaccharides	Traces	Antiviral

Choline is a nutrient needed for cell membrane structure and function. It is necessary for the synthesis of the neurotransmitter acetylcholine, for lipid transport from the liver and for faetal brain development. Choline is present as part of (15%) lecithin or phosphatidyl choline which makes up 73% of the phospholipid present in the yolk. Evidence of its health benefits is still emerging and needs further investigation.

Chickens produce immunoglobulins in blood against all kinds of antigens including bacteria, virus, allergens and other foreign substances. These maternal antibodies are transferred to the yolk to provide immunity to the developing embryo. There is data that suggest specific egg yolk antibodies, such as immunoglobulins (IgA, IgM in the white and IgY in the yolk) have been used as a passive immunization therapy to treat bacterial and viral enteric infections in different animal species including humans (Yegani and Korver, 2010).

In recent years, the poultry industry has been looking for viable alternatives to sub-therapeutic antibiotics. IgY is the most interesting protein in the yolk, amounts to 25 mg per ml and offer potential advantages over antibodies. They are highly specific to the pathogen in question and reported to cause no side effects. IgY can also be effective against viruses. Content and activity of IgY can be improved by boosting the immune system of the hen. Combined with the egg industry's capacity to produce millions of eggs per day and the existing technology for the efficient fractionation and purification of IgY, it is conceivable that kilogram quantities of antibodies could be produced.

Technology is available for the efficient fractionation and purification of IgY. However, consensus on the extraction method is needed, since differences in methods can affect yield, purity, stability, and efficacy of the antibodies. Further, cost-effectiveness also needs to be worked out before any commercial production and administration of these antibodies.

Phosvitin, a yolk protein with metal-binding capabilities could potentially be an antioxidant.

There are three main omega 3 PUFAs; namely linolenic acid (LNA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). It is well established that they play an important role in the prevention of CHD and also infant brain development. The fatty acid composition of the egg yolk can be readily modified by altering the hen's diet. Eggs fed with increased levels of ω-3 PUFAs in the diet, enrich the yolks with these fatty acids. Flaxseed, chia, safflower oil, marine algae, fish and fish oil are rich sources of omega fatty acids that can increase the omega-3 fatty acid content in the egg yolk. These eggs have a darker yellow yolk and contain up to 500-600mg/egg of omega-3 fatty acids (Sim, 2000). Omega 3 enriched eggs, also called as 'designer eggs' are produced and marketed popularly in North America. Other nutrients present in the eggs, provitamins, vitamins and minerals, have also been manipulated. Omega 3s, being unsaturated fatty acids are often enriched with α-tocopherol (vitamin E), a natural antioxidant.

Yolks also contain lutein (37µg/egg) and zeaxanthin (6µg/egg), two natural carotenoids that not just make the yolk yellow, also play an active role in eye health. These carotenoids that accumulate post consumption within the macular region of the human retina function to absorb ultraviolet-blue-wavelength light and act as antioxidants to protect cells from free-radical damage. These phytonutrients have also been shown to be more bioavailable than that from spinach or supplements which is believed to be due to the nature of the lipid matrix of the yolk (Heron and Fernandez, 2004).

The most popular antioxidant used in animal nutrition is α-tocopherol which can be easily deposited in the yolk. Apo-8-ester and canthaxanthin are two carotenoids usually used as antioxidant supplements in layers diet and cover 90% of total carotenoids in the egg. Both natural and supplemented antioxidants are deposited in the yolk according to dietary levels. Increasing levels of carotenoids increases the intensity of yolk colour and does not affect the egg quality in any way. However, supplementing two different coloured pigments has to follow the ratio recommended by the manufacturer in order to avoid off-colours.

Sialyloligosacchaides is another minor constituent present in the egg yolk that is reported to be effective against rotavirus, a virus that causes diarrhoea especially in children and not treatable with antibiotics. Consequently, it is used in infant formulas and baby foods (Juneja, 2000).

FOOD APPLICATIONS

The albumen and yolk possess multiple functional properties which enable a wide range of food applications. They have been called "the cement that holds the castle of cuisine together" due to their ability to bind, leaven, thicken and emulsify. These aspects are beyond the scope of this review and will not be covered herein.

CONCLUSIONS

It is OK now to eat an egg a day. They are a low energy, nutrient-dense, highly digestible, rich source of protein and several multi-functional essential nutrients, vitamin D, folate, B12, selenium, choline and antioxidants. Given the relationship between diet and disease in the modern society, eggs also offer positive health outcomes through its bio-functional opportunities which are being increasingly recognised and commercially exploited. Eggshell membrane is a promising natural biomaterial with many bio-functional virtues for wide ranging applications. Both albumen and yolk also possess a variety of bio-active components. The biologically active proteins of the egg defend the egg in a variety of ways against a variety of microbes. Understanding how they work in this aspect would facilitate their use in various human applications.

Additionally, eggs are an ideal vehicle that can be tailored through feeding to deliver a specific need, less cholesterol, less calories or more specific immune-protein; ω-3 PUFAs; vitamins D, E, A or folate; minerals; antioxidants or any other bioactive nutrient. Egg is more than a small capsule of perfect nutrients that adds nutritional value and multi-functionality to a food product. The possibilities with the egg are tremendous and more research is needed to confirm the health and overall benefits of eggs.

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