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Original Article

Human Health: Nutritional Aspects of Poultry Eggs

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Abstract

Eggs have been recognized as a source of biologically active substances, with significant therapeutic potential. Some of these egg components have been the subject of intense study and are currently produced and used onan industrial scale. Research has allowed a thorough understanding of the egg andits components for the manipulation of egg contents, to further enhance their nutritional and therapeutic potential. Feeding of hens special diets to produce eggs with increased levels of certain nutrients and the immunization of hens to produce specific egg yolk immunoglobulins, capable of preventing and treating bacterial and viral infections are in vogue.

Keywords: Human Health; Composition of Poultry Eggs; Functional Properties of Egg.

Introduction

Eggs have long been recognized as an important source of nutrients, providing all of the proteins, lipids, vitamins, minerals, and growth factors for the developing embryo,as well as defence factors against bacterial and viralinvasion. Eggs are nature's ultimate source of high quality protein. With an estimated one billion under nourished people across the globe – eggs have the power to help provide the much-needed nutrition to the world. A source of high quality protein is essential for foetal development, healthy brain development, improving concentration levels, supporting the body's immune system and is also instrumental in supporting the effectiveness of vaccinations and antiretroviral drugs.

To comprehensively understand the functional usages, the structure and physiology of egg and biosynthesis of eggs is revisited.

Structure and Chemicalcomposition of Hen Eggs

Egg consists of three main parts, the shell, the egg white and the egg yolk. The egg shell is an inflexible, mineralized structure which gives the egg its shape. The shell consists of calcite crystals embedded in a matrix of proteins and polysaccharide complex. It is covered with fine pores, each approximately 10 to 30 µm in diameter, which allow for the exchange of atmospheric gases and water vapour and protects the egg from moisture and invasion of microorganisms. On the inside of the shell is an inner and outer membrane, with a mesh-like structure for obstructing invading microorganisms.

Inside the shell the viscous colourless liquid called the egg white accounts for about 58 per cent of the total egg weight. The egg albumen consists of thin and thick albumen and a chalaziferous layer. The thick albumen is sandwiched between an inner and outer layer of thin albumen. Thethick albumen, with increased viscosity due to a higher concentration of ovomucin, covers the inner thin albumen and chalaziferous layer, keeping the egg yolk in the center of the egg. The chalaziferous layer is a fibrous layerwhich covers the yolk, and is twisted at both ends of theyolk membrane, stretching into the thick albumen and suspending the yolk in the centre of the egg.

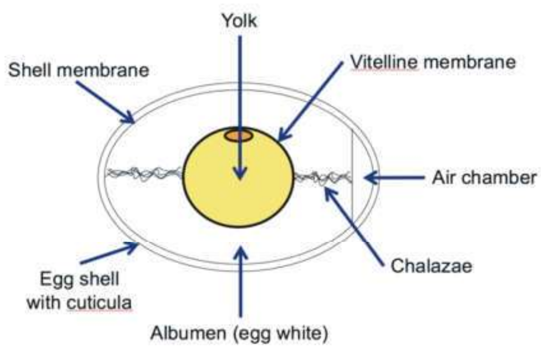

Fig. 1: Structure of Egg (Diagram courtesy Bernd Kaspers). [8]

The weight and composition of a table egg is dependent on heredity, age, season, diet, and other factors. A typical White Leghorn egg usually weighs from 53 to 63g with an average of 55g.

Table 1: Approximate percentage composition of egg white and yolk

Nutrients	Egg White	Egg yolk
Water	88.0	48.0
Protein	11.0	17.5
Fat	0.2	32.5
Minerals	0.8	2.0

I. General Composition

In general, an egg is composed of 9–11% egg shell (shell and shell membrane), 60–63% egg white, and 28–29% egg yolk. The main components are 12% lipids, 12% proteins, and around 75% water, carbohydrates and minerals.Proteins are distributed throughout the egg, but mostof them are present in the egg yolk (44%) and egg white (50%), the remaining 6% in the eggshell and eggshell membrane. Very small amounts of free amino acids have also been reported, presumably for immediate use bythe developing embryo. Egg lipids are found almost exclusively in the eggyolk. Carbohydrates are a minor component of eggs, with 40% of the carbohydrate content being present in the egg yolk, and they are present as free and conjugated forms which are attached to proteins and lipids. Numerous minerals have also been found in eggs, most of them in the egg shell.

II. Egg Shell and Membrane

The egg shell is made up of a matrix consisting of interwoven protein fibers with a high content of sulfur-containing amino acids arginine, glutamic acid, methionine, histidine, cystine, and prolineand calcium carbonate crystals. Approximately 95% of the egg shell is minerals, around 98% of this beingcalcium, along with 0.9% magnesium, and 0.9% phosphorus. The egg shell is covered with a cuticle layer which iscomposed of about 90% protein, with a high content of glycine, glutamic acid, lysine, cystine, and tyrosine, a small amount of carbohydrate, sialic acids and a very small amount of lipid.

III. Egg White

The egg white, or albumen, makes up about 60% of thetotal egg weight. Water and protein are the major constituents of albumen, accounting for about 88% and 11%, respectively. The albumin proteins include Ovalbumin, Ovotransferrin, Ovamucoid, Ovomucin, Lysozyme, Avidin, Ovoglobulin, Ovoinhibitor and Cystatin.

i. Ovalbumin constitutes over half of the total egg white proteins and is a monomeric phophoglycoprotein.
ii. Ovotransferrin has been described as an acute phase protein in chickens, with serum levels increasing during inflammation and infections.
iii. Ovamucoid is a glycoprotein.
iv. Ovomucin protein is responsible for the jelly like character of egg white and the thickness of the thick albumen.
v. Lysozyme is an enzyme capable of lysing or dissolving the cell wall of bacteria. It is composed of 3 components A, B and C.
vi. Avidin is denatured by heat and cooked eggs and do not affect the availability of biotin.
vii. Ovoglobulin is a protein consisting of two components G1 and G2 and both are excellent foaming agents.
viii. Ovoinhibitor is another protein capable of inhibiting trypsin and chymotrypsin.
ix. Cystatin A member of a "superfamily" of cystatins, egg white cystatin belongs to the Type 2 cystatins, which have about 115 amino acids and two disulphide bonds.

Carbohydrates, minerals, and lipids are minor albumen components. The carbohydrates exist both in free form and bound as glycoprotein. Most of the free form carbohydrateis glucose; The major inorganic compounds found in the albumen are sulfur, potassium, sodium, and chlorine, as well as phosphorus, calcium, magnesium, and traces of iron. Lipid isfound in only trace amounts.

IV.Egg Yolk

The egg yolk, surrounded by the vitelline membrane, is composed of yellow yolk, and at the center, white yolk,which originates from the white follicle which maturesin the ovary.

Solid content of yolk is about 50%. Percentage composition of egg yolk on dry weight basis is given below in Table 2.

Table 2:

Lipid	34	77-81
Protein	60	18
Ash	66	2

The major proteins in egg yolk are lipoproteins, which include lipovitellins, phosvitin and low-density lipoproteins. The lipoproteins are responsible for the excellent emulsifying properties of egg yolk, when it is used in such products as mayonnaise. The water soluble fraction (WSF), which contains the livetins, which are lipid-free globular proteins, including γ-livetin, also referred to as immunoglobulin Y. The egg yolk lipids include triglycerides, phospholipids, cholesterol, cerebrosides or glycolipids, and some other minor lipids.

Egg yolk also contains minerals, of which phosphorousis the most abundant. More than half of the phosphorusis contained in phospholipids. The content ofcarbohydrates in the yolk is approximately 1%, most of itas oligosaccharides bound to protein; that which is free isin the form of glucose. Finally, egg yolk contains pigments,primarily carotenes and riboflavin, which are thesource of the colour of the yolk.

Physiology of Egg Production and Biosynthesis af Egg Components

Modern hybrid laying hens can produce more than 300 eggs per year and more than 500 eggs in an extended life cycle. This would not be possible without continuous ovulation, a trait already observed in the ancestors of our modern layers. In the ovary of newly hatched hens more than 12.000 oocytes are present. Of these, only a small proportion will later acquire yolk and develop into mature ovulatory oocytes.

At puberty,these follicles increase in different sizes develop by accumulation of lipids resulting in a hierarchy of follicles which ensures the development of only one pre-ovulatory follicle per day. Hierarchy of large follicles that vary in size. Growth of follicles can be divided into a slow phase (months to years), a rapid phase increasing in protein content (2 month period), or afinal phase (7 to 11 days before ovulation), when the majority of yellow yolk and lipids are deposited. During the final phase, a follicle will increase in size from 0.08g to 16g in weight.

The liver plays an active role in yolk lipid accretion, as it produces lipoproteins that contribute to egg yolk lipids. Yolk constituents are synthesized in theliver in response to hormonal stimulation, some as protein precursors which are later enzymatically modified, andare transported to the follicular walls in the blood. The follicle undergoes several changes, including a separation of the cells of the granular layer, in order to facilitate the transfer of material to the yolk, which occurs via receptor mediated endocytosis, producing yolk granules.

When sufficient yolk has accumulated, the follicle then enters the oviduct. As it travels through the oviduct the vitelline membrane of the yolk and chalazal layer of the albumen are added, followed by the secretion of the albumen.

Other nutrients,such as water, sugars, proteins, vitamins, and minerals arealso deposited into the yolk from the hen's blood. Follicles are said to be "mature" when they are capable of producing progesterone, which is released from the largest follicle. Release of progesterone will trigger the ovulation process.

Follicular maturation typically takes longer than 24 hours, and so the ovulatory cycle is set back slightly each day. The matured follicle is ovulated and drops from the ovary into the egg-laying tract as the pulletreaches laying age (around 20 weeks).

Major Hormones Involved in Egg Production

The production of eggs is orchestrated through the action of organs, such as the brain (endocrine), liver (lipoprotein), and skeletal system (calcium). Light stimulation causes the release of follicle stimulating hormone from the pituitary, causing an increase in the growth of ovarian follicles. Upon reaching sexualmaturity, the ovum is released by the action of leutinizinghormone secreted by the pituitary gland.

Table 3:

Hormone	Production	Function
Luteinizing Hormone	Anterior Pituitary	Ovarian hormone production
Follicle Stimulating Hormone	Anterior Pituitary	Early follicledevelopment
Progesterone	Ovarian Follicle (Granulosa cells)	Oviduct growth. Initiate ovulation throughfeedback

Rupture of the follicle wall leads to the release of the ovum which is captured by the infundibulum and thus funnelled into the reproductive tract. The avian oviduct is a tubular organ extending fromthe ovary to the cloaca. In laying hens, the oviduct is 40–80 cm long, consisting of five portions: infundibulum, magnum (albumen-secreting portion), isthmus, uterus, andvagina. The oviduct ensures smooth passage of the egg and secretes extracellular matrix components to surround the egg albumen. Fertilization, formation of the vitelline membrane and of the first layer of albumen of the egg takes place in the infundibulum. The majority of albumen is produced during the passage through the magnum and subsequently egg shell membranes are formed in the isthmus.

The final step of egg formation, the production of the egg shell, takes place in the uterus or shell gland before the egg is released by oviposition. This entire process takes 24-27 hours with most of the time required for shell formation. It takes approximately 2 grams of calcium to form an egg shell. Prior to calcification, the egg takes up water and pigments into the albumen from the tubular glands. Pigment deposition occurs in the last three to five hours the egg spends inthe shell gland. The laying of an egg is known as oviposition, which occurs in sequences. The process of laying an egg takes approximately 25 hours from the time of ovulation until the egg is laid.The next ovulation takes place 15-60 minutes after oviposition. (Diagram courtesy Bernd Kaspers).

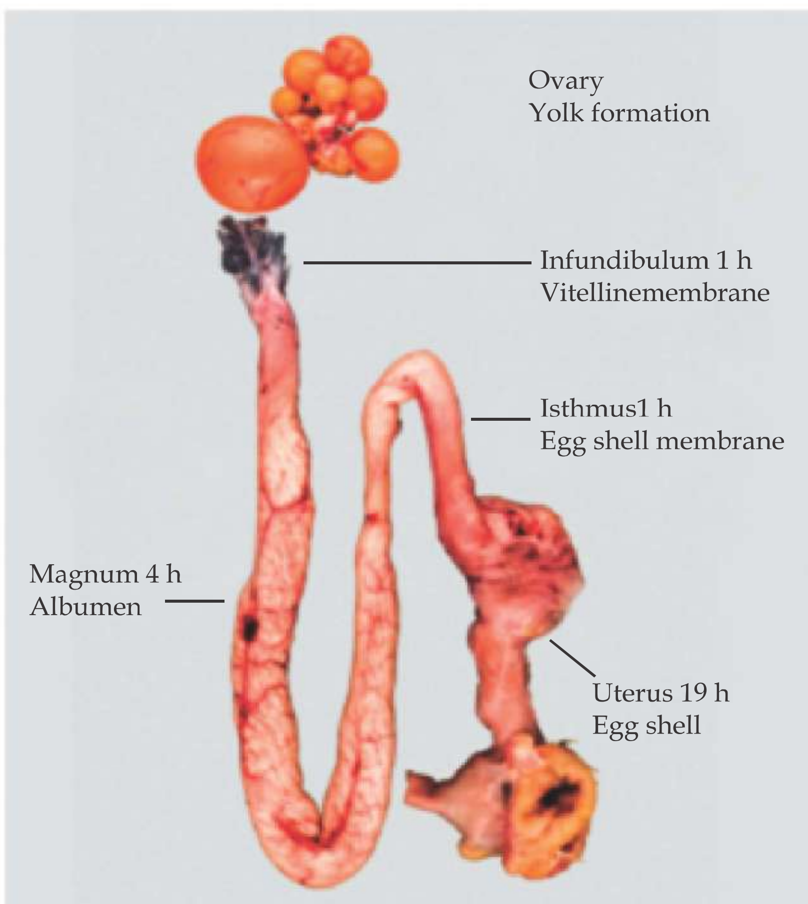

Fig 2: Egg formation in reproductive tract of hen (Image courtesy Bernd) [8]

Biological Attributes of Egg Constituents

A. *Egg Shell*

1. Egg Shell Calcium and Matrix Proteins

So far egg shells were considered waste but it has many applications as food ingredient. Chicken egg shell consists of mainly calcium carbonate and rest is an organic matrix consisting of glycoprotein and proteoglycans. Egg shell calcium has been proposed for pharmaceutical applications for calcium deficiency therapies in humans, and in animals forbone mineralization and growth. In humans the use of the egg shell powder resulted in decreased pain and increased bonemineral density. Some egg shell matrix proteins also possess calcium binding properties. Egg shell calcium is proposed as an excellent calcium supplement to increase bone mineral density in individuals with osteoporosis.

2. Egg Shell Membrane

Egg shell membrane is composed of collagen-like proteins (collagen types I and V). The membrane proteins (peptides) arecurrently utilized as a cosmetic ingredient for their emollient properties. Egg shell membranes also contain antimicrobial substances. Lysozyme activity was reportedin the outer and inner membranes.

B. Egg White

Various biological activities are associated with the egg white, and are summarized in Table3.

1. Ovalbumin: Functionally, ovalbumin is important for the gelling, foaming, and emulsifying properties of egg white; Ovalbumin is also a key reference protein for vaccination experiments. Ovalbumin displays sequence and three-dimensional homology to the serpin super family, but unlike most serpins it is not a protease inhibitor. Ovalbumin, the major protein constituent of chicken egg whites, is a glycoprotein that is sufficiently large and complex to be mildly immunogenic. Consequently, it is widely used as an antigen for immunization research. It has been suggested that ovalbuminmay serve as a source of amino acids for the developing embryo. Ovalbumin may also possess some immunomodulatory activity, as it was found to induce the release of tumor necrosis factor (TNF) alpha in a dose-dependent mannerin vitroand immunogenic ovalbumin peptides have been used to enhance immune responses for cancerimmunotherapy.

Ovalbumin was found to possess a strong antioxidant activity against linolenic acid and docosahexaenoic acid (DHA). A vaso relaxing peptide (ovokinin) was isolated from the peptic digestion of ovalbumin. Two angiotensin I converting enzyme (ACE)-inhibitorypeptides were also identified in ovalbumin. Furthermore, phagocytic activity of macrophages wasincreased by the addition of some peptides, derived by peptic and chymotryptic digestions of ovalbumin, respectively.

2. Ovotransferrin (Conanlbumin): Belonging to the transferrin family, a group of iron-binding proteins which are widely distributed in various biological fluids. Its suggested function is as an iron scavenger, preventing availability of iron to microorganisms, and as an iron delivery agent. Ovotransferrin has been suggested as a natural food antimicrobial, and its antibacterial activity has been shown against a wide spectrum of bacteria. Among the several protective functions of Ovotransferrin, the most important one is likely to be the antibacterial activity, which is directly related to the Ovotransferrin's ability to bind iron ($Fe3+$), making it unavailable for bacterial growth.

It has also been shown that ovotransferrin possesses both antiviral activity, against Marek's disease virus in chicken embryo fibroblasts, as well as antifungal activity, against species of Candida. Ovotransferrin is a superoxide dismutase-mimicking protein exhibiting a superoxide radical with scavenging activity. Ovotransferrin has also been described as an acute phase protein in chickens, with serum levels increasing during inflammation and infections. It has been suggested thatacute phase proteins may facilitate the biological activities of phagocytic cells. It is demonstrated that ovotransferrin has immunomodulating activity against T-cells and macrophage-stimulating activities in vitro, indicating that they also can be good candidates for pharmaceutical use in humans.

3. Ovomucin: Hens' egg white ovomucin is a macromolecular and heavily glycosylated glycoprotein, consisting of peptide-richand carbohydrate-rich subunits. Ovomucin serves physical functions such as maintaining the structureand viscosity of the egg white albumen thus servingto prevent the spread of microorganisms and possessing good foaming and emulsifying properties. However, it has also demonstrated several biological applications. Anti-haemagglutination activity of ovomucin against influenza virus was reported. Ovomucin also showed anti-bacterial activity. Ovomucin was found to have inhibitory activity against colonization of Helicobacter pylori. Ovomucin peptides may also act as immunomodulators, showing macrophage-stimulating activity in vitro. The cytotoxic effect of β-ovomucin from egg white on cultured tumor cells such as SEKI cell (human melanoma cell) and 3LL (Lewis lung cancer cell) has also been reported. Finally, ovomucin was also found to inhibit cholesterol uptakeand reduce serum cholesterol in displaying hypocholesterolemic activity.

4. Ovomucoid: Ovomucoid is a glycoprotein comprised of 186 amino acids. It is relatively resistant to treatment withheat or digestive enzymes, and it is this stability that hasled to its being one of the main egg white allergens. Ovomucoid is well known as a "trypsin inhibitor". However, the negative functions of ovomucoid can be eliminated if the protein is cut into small peptides.

The incorporation of ovomucoid into polymeric microparticles, to overcome the degradation of protein drugsby proteolytic enzymes, has been seen and it is found that when ovomucoid was included, the stability of insulin was increased significantly. It was reported that ovomucoid has a bio-specific ligand, which can be used as a drug delivery agent.

5. Lysozyme: Lysozyme is a ubiquitous enzyme, present in almost allsecreted body fluids and tissues of humans, as well asplants, which plays an important role in the natural defense mechanism. The most plentiful source, however, hens' egg white, containing around 0.3–0.4 g of lysozyme per egg. This phenomenon has found a practical application inthe food processing industry, in medicine and pharmaceutical industry. The use of lysozyme in the food processing industry is connected primarily withits application as a natural preservative. The enzyme is widely used as a preservative for meat, fish and their products, for milk and dairy products, aswell as for fruit and vegetables. The pharmaceutical industry uses this enzyme in the manufacture of adjuvant drugs for antibiotics and analgesics inviral and bacterial infections,Lysozyme monomer exhibits strong antibacterial activity against Gram-positive organisms. in the treatment of leukemia and neoplastic diseases. Lysozyme has also been added to oral healthcare products, such as toothpaste, mouthwash and chewinggum to prevent infections in the oral mucosa.Finally, lysozyme has also been shown to act as animmune-modulating and immune-stimulating agent, enhancing immunoglobulin production, and regulatingand restoring the immune responses in immune-depressedpatients undergoing anti-cancer treatments andas an anticancer agent, the inhibitory action of lysozyme being demonstrated in a number of experimental tumors.

6. Avidin: Chicken avidin is a tetrameric glycoprotein, with an extremely high affinity for the water soluble vitaminbiotin. The unique feature of this binding is the strength and specificity of the formation of the avidinbiotin complex. The high affinity of avidin for biotin has been widely used as abiochemical tool in molecular biology, affinity chromatography, molecular recognition and labelling, Enzyme Linked Immuno Sorbent Assay (ELISA), histochemistry and cytochemistry.

It has been suggested that avidin possesses antimicrobial properties, and it has been found to inhibit the growthof biotin-requiring bacteria and yeasts. Avidin has also been found to be useful in medical applications, to localize and image cancer cells and to pre-target drugs to tumors. Avidin may be a promising vehicle for the delivery of radioisotopes, drugs, toxins or therapeutic genes to tumors.

7. Cystatin: All true cystatins inhibit cysteine peptidases of the papain family, and some also inhibit legumain family enzymes. These peptidases play key roles in physiological processes, such as intracellular protein degradation (cathepsins B, H and L). Moreover, the activities of such peptidases are increased in pathophysiological conditions, such as cancer metastasis and inflammation. Additionally, such peptidases are essential for several pathogenic parasites and bacteria. Thus cystatins not only have capacity to regulate normal body processes and perhaps cause disease when down-regulated, but may also participate in the defence against microbial infections.

Egg white cystatin has been shown to possess antibacterialactivity, preventing the growth of group A streptococcus, Salmonella typhimurium. It has been suggested that cystatins may not only havea general function of protecting cells against uncontrolledactivities of their own proteinases, but may also protect against viral proteinases responsible for viral infection. Similar cysteine protease inhibitors have shown antiviral activity against herpes simplex virus, poliovirus and human rotavirus. The use of chicken cystatin has also been suggested for food preservation applications, including itsuse to inhibit autolysis or gel softening in seafood.

8. Ovomacroglobulin (Ovostatin): Ovomacroglobulin, also referred to as ovostatin, is a glycoprotein composed of four subunits, each with a molecular weight of 175 000 Da, joined in pairs by disulfide bonds. ovostatin inhibits metalloproteinases in preference to proteinases of other classes. The antimicrobial effects of ovomacroglobulin due toits proteinase inhibitory action against Serratiaand Pseudomonas, have been studied. It was found to reducecorneal destruction in an experimental keratitis model in rabbits, as well as to accelerate wound healing.

9. Ovoinhibitor: Another proteinase inhibitor in egg white, ovoinhibitor isa glycoprotein composed of a single 447-amino acid polypeptide. Likeovomucoid, ovoinhibitor is a serine proteinase inhibitor, inhibiting enzymes such as trypsin, chymotrypsin, and elastase, as well as various bacterial and fungal proteinases. It is shown that this anti-protease plays a significant role in antibacterial egg defence against Bacillus spp., preventing contamination of table eggs (nonfertilized eggs) and protecting the chick embryo (fertilized eggs). Ovoinhibitor has been found to inhibit the formation ofactive oxygen species by human polymorphonuclear leukocytes, which are associated with inflammatory diseases, mutagenicity and carcinogenicity.

Table 4: Biological Properties of Egg white Proteins.

Protein	Properties
Ovomucin	Antiviral activity
	Antiviral activity of ovomucin-derived fragments
	Anti-tumor activity
	Immunomodulating activity Hypocholesterolemic activity
Ovotransferrin	Antibacterial activity
	Antimicrobial activity of ovotransferrin-derived peptide
	Antiviral activity
	Antifungal activity
	Immunomodulating activity
	Enhancement of activity of certain antibiotics
Ovalbumin	Anti-mutagenic and anti-carcinogenic activity
	Immunomodulating activity
	Antioxidant activity
	Anti-hypertensive activity of ovalbumin-derived peptides ovokinin and ovokinin (2-7)
	Angiotensin 1 converting enzyme (ACE) inhibitory activity of ovalbumin-derived peptides
	Immunomodulating activity of ovalbumin-derived peptides
Ovomucoid	Serine proteinase inhibitor
	Drug delivery to small intestine
	Biospecific ligand to lectins in gastrointestinal tract
	Immunomodulating activity
Lysozyme	Antibacterial activity
	Enhanced antimicrobial activity when coupled to hydrophobic carrier or phenolic aldehyde
	Antimicrobial action of lysozyme-derived peptides
	Application as a food preservative
	Protection against periodontis-causing bacteria when added to oral health care products
	Antiviral activity
	Anti-inflammatory activity
	Immunomodulating and immune-stimulating activity
	Anti-tumor activity
Avidin	Antimicrobial activity
	Pre-targeting and drug delivery of anti-cancer drugs
	Application in adoptive immunotherapy
	Drug delivery to brain

Cystatin	Cysteine proteinase inhibitor
	Antibacterial activity
	Inhibition of growth of P. gingivalisby cystatin-derived peptides
	Immunomodulating activity
	Inhibition of tumor invasion
Ovomacroglobulin	Serine, cysteine, thiol, and metallo proteinase inhibitor
	Antibacterial activity
	Enhancement of wound healing
Ovoinhibitor	Serine proteinase inhibitor
	Antiviral activity
	Potential anti-inflammatory and anti-mutagenic activity
	Protein purification applications

Source: Mine Y. and r Kovacs-Nolan J. 2006.

C. EGG Yolk

Several biological activities are associated with egg yolk components, and are summarized in Table 4.

1. Immunoglobulin (Ig) Y: Immunoglobulin (Ig) Y is the functional equivalent of IgG, the major serum antibody in mammals. It is transferred to the developing embryo, to give acquired immunityto the chick. The use of egg yolk antibodies presents many advantages over those produced in mammals, including being less invasive and less stressful on the animal. It is also more cost-efficient, and has a higher yield of antibodyper animal. IgY antibodies have many advantages over IgG antibodies such as strong avidity, scalable productivity, low assay background, and applicability to many immuno assays providing a strategy for improvement of assay performance and accuracy. IgY has been produced against several bacteria and viruses, and has been shown to bind to and inhibit the infection and disease symptoms, in vitro and in vivo, of many human and bovine viruses.

Chicken anti-venom IgY has been produced, for treatment of snake and spider bites, and was found to have a higher bioactivity than anti-venom raised in horses. IgY also has a lower likelihood of producing significant clinical side effects, such as serum sickness and anaphylactic shock, which can occur upon administration of mammalian serum proteins. The use of IgY has also been examined to replace the anti-inflammatory drugs used to treat Crohn's disease and ulcerative colitis. Yogurt fortified with IgY urease made from egg yolk was developed to decrease H. pylori. IgY has been suggested for use in targeting cancer cells, to act as a carrier for anti-tumor drugs.

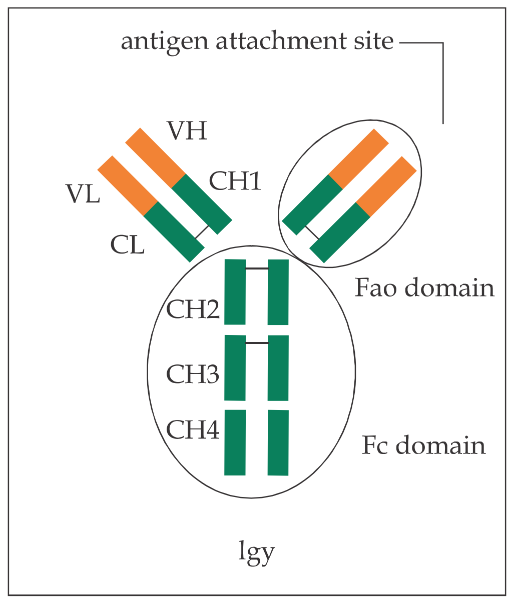

Fig. 3: IgY- Schematic diagram.

2. Phosvitin: Phosvitin is a highly phosphorylated protein containing 10% phosphorus and6.5% carbohydrates. Ninety-five percent of the iron in eggs is present inthe yolk and is bound to phosvitin; however, its bioavailability is very low. Research indicates that phosvitin has the potential to be used as a melanogenesis inhibitor in the food and cosmetics industry. Novel functional phosvitin phosphopeptides may have potential applications as nutraceuticals. Phosvitin also demonstrated a capacity to inhibit ironcatalysis of phospholipid oxidations. Thus, phosvitin could be useful in foods as a natural antioxidant.

3. Lipoproteins (Low Density Lipoproteins, LDL): The low density lipoproteins (LDL) fraction of yolk plasmais composed of 89% lipid and 11% protein. Thelipid content of LDL is mainly triacylglycerol, phospholipids and small amount of cholesterol.

LDL are the main contributors to yolk interfacial and emulsifying properties. These capacities areclearly due to the LDL structure through interactions between amphiphilic apoproteins and phospholipids. This permits the formation and the stability of food emulsions made with yolk. LDL was alsoshown to enhance the production of IgM in human-humanhybridomas. LDL is widely used as a cryoprotectant for bull semen and it has shown better efficiency than commercial extenders.

4. Sialic Acid: Sialic acid is a general term for derivatives of neuraminic acid which have an acyl group on the amino nitrogen. The most widely distributed sialic acid in nature is N-acetylneuraminicacid (Neu5Ac). Egg yolk membrane and chalaza has been found as a source of sialic acid, and was found to be anexcellent source for the large scale preparation of Neu5Ac. Sialic acids possess many biological functions, including acting as receptors for microorganisms, toxins, and hormones, and masking receptors and immunological recognition sites of molecules and cells. Sialic acid may act as an anti-inflammatory agent. Asialic acid analogue, zanamivir, has demonstrated potent antiviral effects, and was found to reducethe symptoms of influenza infections in humans, byinhibiting influenza A and B virus neuraminidases, enzymes essential for the release of virus from infectedcells.

5. Sialyloligosaccharides: Several sialyloligo-saccharides in chalaza, egg yolk membrane have been isolated byacid hydrolysis or protease digestion. These sialyloligosaccharides are likely to be naturally present as glycoproteins or glycopeptides. Sialyl-glyco-conjugatesand sialyl-glycoproteins have been reported to play various important roles in animal and human tissue cells. Sialyl-oligosaccharides also inhibited Salmonella infection by inhibiting the entry of bacteria through the gut.

6. Yolk Lipids: Dry egg yolk contains approximately 60% lipids, and of this around main is triglyceride, followed by phospholipid, and a little amount of cholesterol. The fatty acid composition ofthe lipid fraction of egg yolk varies, and is influenced bythe type of fat in the hen's diet. Egg yolk lipids have found numerous applications in the food, cosmetic, pharmaceutical and nutraceutical industries. Egg yolk lipids are natural surfactants, and have beenapplied in the food industry as emulsifying, wetting, and dispersing agents, releasing agents, sealants and lubricants.

Yolklipids have been shown to possess antioxidant activity infish oil, vegetable oil, and animal oil, both alone and inconjunction with primary antioxidants. Eggyolk lipids have also been used in the cosmetic industry,due to their non-toxic nature, as they replenish lipid deficiencyin the skin and closely resemble skin lipids. A fat emulsion derived from egg yolk lipids is often used as a carrier of fat soluble drugs. Cholesterol is an important component in cell membranes and is needed for the growth of infants. As well, itis a precursor of bile acids, sex hormones and cortex hormones. The supplementation of infant formulas with egg yolk lipids has been suggested to more closely resemblethe mother's milk; Egg yolk cholesterol has also been suggested for use in the treatment of Smith-Lemli-Opitz syndrome, in which cholesterol biosynthesis is reduced resulting inreduced plasma and tissue concentrations.

7. Phospholipids: Phospholipids (PLs) are lipids which contain phosphate and have a glycerol-phosphate backbone. Used to fortify Infant Formula – Rich in Omega 3 and Omega 6 fatty acids, which are needed for brain and eye development. It has been discovered that the PL found in egg yolk is almost equivalent to the PL found in human breast milk. The PL in yolk also contains cholesterol and choline, fundamental nutrients for a baby's development.

The specific PL components namely arachidonic acid (AA), docosahexaenoicacid (DHA), and choline, which are importantin the maintenance of normal neural functions like in membrane integrity, modulation ofthe membrane, and activation of immune cells have shown to help prevent dementia. It is also shown that they protect against liver failure – Studies have shown that phospholipids can help to repair liver damage caused by toxins in substances like drugs, medication, alcohol, fatty foods, and viruses. It is also having cosmetic applications – The bilayer shapes formed by egg phospholipids are easily absorbed by the skin and can aid in the regeneration of skin.

Table 5: Biological Properties of Egg Yolk Components

Protein	Properties
Immunoglobulin Y	Antibacterial activity Antiviral activity Reduction of dental caries Anti-venom applications Anti-inflammatory action
Phosvitin	Cancer targeting and drug delivery of anti-tumor drugs Enhancement of calcium binding by phosvitin-derived peptides Antioxidant activity
LDL	Immunomodulating activity Cryoprotectant
Sialic acid	Receptor functions Anti-inflammatory activity
Sialyloligosaccharides	Antiviral activity Antibacterial activity
Yolk lipids	Antioxidant activity Important for maintenance of cell membranes Drug carrier
Phospholipids	Treatment of Smith-Lemli-Opitz syndrome Drug delivery to tumors and brain (via liposomes) Reduction of necrotizing enterocolitis in infants Reduction of serum cholesterol Increase in acetylcholine concentrations, and improvement in memory retention and brain function Antiviral activity Source of DHA and AA, which possess anti-tumor, anti-thrombic anti-inflammatory, anti-hypertensive, vasodilatory, and hypolipidemic effects

Source: Mine Y. and r Kovacs-Nolan J. 2006.

Categorization and Definitions of Functional Foods

In general, a large number of food products can be defined as functional foods, i.e. foods containing specific nutrients and/ or non-nutrients, and affecting human health positively, over what is traditionally known as nutritional effects. In fact, it is very difficult to have a precise and universally accepted definition of these foods. Consequently, it has been suggested to understand the term "a functional food" as a new idea, rather than a defined product [Bellisle et al., 1998; Diplock et al., 1999; Roberfroid, 2000, 2002].

Accordingly, an ideal functional food was considered to be:

1. A conventional or everyday food;
2. Consumed as a part of the conventional diet;
3. Composed of naturally occurring components;
4. Enhancing target function(s) beyond its nutritive value;
5. Reducing the risk of disease,and
6. Having sound, scientifically-based and verified claims.

The designation of functional foods was first introduced in Japan, in the 1980s, and refers to processed foods containing ingredients that aid specific bodily functions in addition to being nutritious. Eventually USA and Europe also started the process of recognising legally the functional foods category. The definitions of functional foods by different agencies ranged widely as follows:

1. Foods that provide health benefits beyond basic nutrition.
2. Foods that, by virtue of physiologically active components, provide health benefits beyond basic nutrition.
3. Those in which the concentrations of one or more ingredients have been manipulated or modified to enhance their contribution to a healthful diet.

The emerging food spectrum is very wide but functional foods are still preferred by consumers over other commonly used terms such as neutraceuticals or designer foods. However, now public awareness about other food categories has to be created to avoid any confusion.Ministry of Health & Family Welfare has drafted the Food Safety and Standards (Food or Health Supplements, Nutraceuticals, Foods for Special Dietary Uses, Foods for Special Medical purpose, Functional Foods, and Novel Food) Regulations, 2015.

Hens' Eggs as Functional Food

A. Effect on Brain: Phospholipids are an important component of egg yolk lipoproteins, and also the major constituent in cell membranes of all living organisms. Phospholipids provide the necessary interface for nutrient transport, due to their amphipathic properties, and are rich in long chain PUFA, such as DHA and arachidonic acid. Neural tissues, such as those in brain and retina, are highly concentrated, with DHA constituting over 50 and 70% of fatty acids in brain synaptosomal membranes and rod outer segments of retina, respectively DHA is involved in maintaining membrane fluidity, signal transduction, protein signaling, and gene expression. Accretion of DHA in the human brain is also high during periods of brain growth spurt, which starts during the third trimester of pregnancy and extend through the first 2 years of life. An average egg could provide over 300 mg of long chain PUFA, and could well be included in the diet of pregnant and nursing women as well as the diet of weaning toddlers.

Chicken eggs are a rich source of choline (associated with phosphatidyl choline in phospholipids). Choline is responsible for the structural integrity and signaling function of phopholipid-rich cell membranes. One large egg contains about 300 mg of choline, which provides 60% of the recommended daily intake of choline for adults, including pregnant and lactating women. Animal studies have found that choline plays an essential role in the development of brain function, memory and learning ability in mice.

B. Effect on Vision: Age–related macular degen-eration is a debilitating eye disorderof the elderly, resulting in irreversible blindness. Two carote-noids, leutin and zeaxanthin, accumulate in the macularregion of the eye and have recently received attention for their potential role in delaying age–related macular degeneration. Lutein and zeaxanthin are two newly-recognized nutrients that have put eggs in the "functional foods" category. A functional food is one that provides health benefits beyond its basic nutrient content.

Besides the conditionally-essential nutrients L-carnitine, coenzyme Q10, α-lipoic acid, choline and taurine, widely diffused in animal products. There are scientific evidences of functional foods which support the observation that functional foods from animal sources enhance human health.

Leutin and zeaxanthin are able to absorbblue light striking the retina, which is thought to initiatedegeneration of the retinal membranes. Egg yolk contains leutin and zeaxanthin and they are more bio-available from this source than fromplant sources of carotenoids. Eating eggs resulted in increases in plasma leutin and zeaxanthin. These also possess antioxidant propertiesand protect the PUFA-rich retinal membranes fromphototoxic damage.

C. Effect on Cell Regulation: Sphingolipid content of eggs has been reported to be the highest of any food at 2250 umol/kg. Sphingolipids are critical for the maintenance of membrane structureand modulate the behavior of extracellular matrix proteins. There is no known nutritional requirement for sphingolipids; nonetheless, they are hydrolyzed throughout the gastrointestinal tract to the same categories of metabolites (ceramides and sphingoid bases) that are used by cells to regulate growth, differentiation, apoptosis and other cellular functions. Studies with experimental animals have shown that feeding sphingolipids inhibits colon carcinogenesis, reduces serum LDL cholesterol and elevates HDL, suggesting that sphingolipids represent a "functional" constituent of food. Sphingolipid metabolism can also be modified by constituents of the diet, such as cholesterol, fatty acids and mycotoxins (fumonisins), with consequences for cell regulation and disease.

Enriched/Designer Eggs: Egg Nutrient Modulation

Animal fats including egg lipids are important sources ofmany nutrients. Modern agriculture with its emphasis on production resulted in drastic changes in fatty acid content of food products resulting in an imbalance of polyunsaturated and saturated fatty acids, antioxidant vitamins and a wide ratio of n-6:n-3 fatty acids in the current food supply including eggs. The dietary recommendations set forth by health agencies include reduction in total fat intake to 30% ofcalories with an increase in monounsaturated fatty acids and PUFA to 15 and 10% of calories and a balance of PUFA to saturated fatty acids close to 1.

The egg industry is aligning toproduce and market eggs with more balanced PUF Acontaining both n-3 and n-6 fatty acids. The health benefits of omega-3 fatty acids are significant, suggested for the prevention and treatmentof hypertension, arthritis, autoimmune disorders, as wellas inhibiting certain cancers, and being essential for foetal brain and visual development. "designer eggs," are available and are capable of supplying around 600 mg oftotal omega -3 fatty acids, which is approximately equivalent to a 100 g serving of fish. Chickens are monogastric and the lipid nutrient composition of the dietalters the content of fatty acids and other fat-soluble vitamins and pigments in eggs. The feeding of conjugated linoleic acid (CLA) to hens' has also been suggested as amethod to manipulate the fatty acid profile of egg yolk. The enrichment of other minor nutrients through feed manipulation is also done.

Herbal Enriched Designer Eggs (HEDE): Herbal enriched eggs can be produced by the incorporation of herbal active principles like, allicin, betaine, eugenol, lumiflavin, lutein, sulforaphane, taurine and many more active principles of the herbs, depending upon the herbs fed to the hens . Moreover, these eggs had about 25% lesser cholesterol in their yolks, compared to ordinary eggs. Feeding such HEDE to human volunteers has resulted in significant reduction in their Triglycerides (TG) levels, increased the good HDL cholesterol, improved immunity and haematocrit. (Narahari 2004).

Cholesterol designer eggs: At present health conscious consumers are suffering from cholest-rophobia thus the demand of low cholesterol eggs is very high which can be achieved either by reducing the amount of cholesterol per egg, by reducing the size of the yolk or by altering the lipid profile of the yolk. However, the idea of cholesterol-enriched eggs for the future is also mooted.

Vitamin-E enhanced designer eggs: Vitamin E enriched eggs can be produced with a higher amount of vitamin-E as compared to normal eggs by feeding hens on diet high in vitamin-E. The higher contents of vitamin-E can be obtained by supplementation of poultry feed in the form of natural sources found in butter, milk, vegetable and nut oils. The extra addition of vitamin-E in the diet of hens is beneficial as Vitamin E reduces free radicals in blood, decreases risk of cancer and ageing process due to the reduction in the formation of the free radicals formation, it may reduce the risk of heart disease since it is an antioxidant.

Pigment fortification of yolk: Fortification of eggs with carotinoid is the new concept in the field of the designer eggs. The pigment enriched eggs looking attractive to the consumers due to its beautiful nature of more intense yellow colour. Canthaxanthin is a carotenoid usually used for the production of pigment enriched yolk by the help of the feeding of the hen. There are a number of other carotenoid which may be used for fortification in egg consist of lycopene. Blue green algae is the another source of carotenoid which is basically high in protein content but also provides certain pigment like spirulina pigment and can be utilized for enhancing the carotenoids content in the egg yolk. Normally carotenoid in egg yolk of poultry are of hydroxyl compounds which is called xanthophylls. While lutein and zeaxanthin are the two most recurrent xanthophylls found in egg yolk and their functional attributes are encouraging feed fortification to prevent macular degeneration, protective effect to retina etc.

Pharmaceutical designer eggs: Through the genetic manipulation hens are capable to produce certain pharmaceutical compounds and these compounds can be harvested through eggs i.e., insulin which are used for treatment of diabetes. Other techniques are also adopted for the development of antibody enriched eggs and antivenom IgY harvesting etc. For that the hens are given an antigen and after its administration, hens develops antibody against the antigen which are then concentrated in eggs.

Immunomodulating eggs: The eggs naturally contains certain specific compound like lysozyme (G1-globulin), G2 and G3-globulin, ovomacro etc. The globulin antibodies are natural antimicrobials and immunostimulants in the egg that can be utilized in the cure of immunosuppressed patients like AIDS patient. Like other component of eggs modification the levels of I gY like immunoglobulin's in the egg can be improved by dietary manipulation. The properties of the immunomodulating of eggs can further improve the eggs by use of omega-3 fatty acid and antioxidants. Certain other herbs like rosemary, turmeric, garlic, fenugreek, spirulina, ashwagandha are also possessing immunomodulating properties so by the use of that kind of herb in the feed of the hen also improve the efficiency of the immunemodulating properties of the eggs.

Mineral and Vitamin enriched designer eggs: Many types of minerals can also be enriched in the production minerals enriched designer eggs. Among these selenium and iodine are one of them followed by chromium and copper. This can be achieved by the dietary manipulation of hen's diet. These trace minerals are very important for human health because the deficiency of these trace minerals leading to development of certain deficiency disease. Vitamin D is an essential component of vertebrate nutrition, and epidemiological surveys confirm a chronic vitamin D insufficiency in the human population. Eggs are one of the few natural sources rich in vitamin D, containing both vitamin D (D) and 25-hydroxyvitamin D (25(OH)D). 25-Hydroxyvitamin D is especially useful because it provides five times the relative biological activity of vitamin D. The addition of higher levels of D and 25(OH)D in the hen's feed produced eggs with sufficient vitamin D to meet the recommended daily requirements of adults and children.

Summary

Egg is the largest biological cell known which originating from one cell division and is composed of various important chemical substances that form the basis of life. Therefore ,the avian egg is considered to be a store house of nutrients such as proteins, lipids, enzymes and various biologically active substances including growth promoting factors aswell as defence factors against bacterial and viral invasion.

In the last decade, numerous extensive studies characterizing biophysiological functions of egg components and seeking novel biologically active substances in thehen eggs have been conducted. Hen eggs contain various biologically active substances with specific benefits for human health and would be ideal sources for medical, cosmetic, nutraceutical and food-fortification applications. Therefore, wrapping-up with the following message that can be spread to increase awareness amongst the masses about health benefits of eating eggs:

1. Eggs are among the most nutritious foods on the planet.
2. High in cholesterol, but don't adversely affect blood cholesterol.
3. Raise HDL (The "Good") Cholesterol.
4. Contain Choline — an important nutrient that most people don't get enough of.
5. Are linked to a reduced risk of heart disease.
6. Contain Lutein and Zeaxanthin — antioxidants that have major benefits for eye health.
7. Omega-3 or Pastured Eggs lower triglycerides.
8. High in Quality Protein, with all the essential amino acids in the right ratios.
9. Doesn't raise your risk of heart disease and may reduce the risk of stroke.
10. Are filling and tend to make you eat fewer calories, helping you lose weight.

Source: https://www.healthline.com/nutrition/10-proven-health-benefits-of-eggs

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