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Nutritional approaches for production of designer egg: A review

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Abstract
In the present scenario people are very much health conscious as a result demand of quality and functional foods worldwide increasing continuously. They are committed to maintain an active and healthy lifestyle, avoid of serious health and medical issues. Healthy lifestyle is always related to nutrient requirement. Poor nutrition not only retarded the physical and mental growth but also the immunity. Functional foods are intended to be consumed as part of the normal diet but offer the potential of enhanced health or reduced risk of disease. Eggs are considered as the nature's most complete food. Egg is an encapsulated source of macro and micronutrients that meet all requirements to support embryonic development until hatching. The perfect balance and diversity in its nutrients along with its high digestibility and its affordable price has put the egg in the spotlight as a basic food for humans. However, fulfilling the demand of the consumer is to reduce the cholesterol content and enhancing the health positive nutrients in the egg brought the concept of designer egg.

Keywords: Health conscious, immunity, functional foods, cholesterol, designer egg

1. Introduction
Poultry sector in India is broadly divided into two sub-sectors – one is a highly organized commercial sector with about 80% of the total market share and the other being unorganized with about 20% of the total market share. The unorganized sector also referred to as backyard poultry and plays a key role in supplementary income generation and family nutrition to the poorest of the poor. The total Poultry in India is 851.81 Million in 2019, increased by 16.8% over previous Census. India ranks 3rd for egg production in the world. The egg production in the country is increased around 103.32 billion no's in 2019. Among all sectors of animal husbandry, poultry industry is one of the fastest growing industries (Satapathy *et al*., 2017) [19].

2. Egg Nutrition Facts
Eggs are of particular interest from a nutritional point of view, gathering essential lipids, proteins, vitamins, minerals and trace elements, while offering a moderate calorie source (about 140 kcal/100 g), great culinary potential and low economic cost. Indeed, eggs have been identified to represent the lowest-cost animal source for proteins, vitamin A, iron, vitamin B_{12}, riboflavin, choline and the second lowest-cost source for zinc and calcium. Egg proteins are distributed equally between egg white and egg yolk, while lipids, vitamins and minerals are essentially concentrated in egg yolk (Figure 1). Water constitutes the major part of egg (Figure 1) and it is noteworthy that the egg is devoid of fibers.

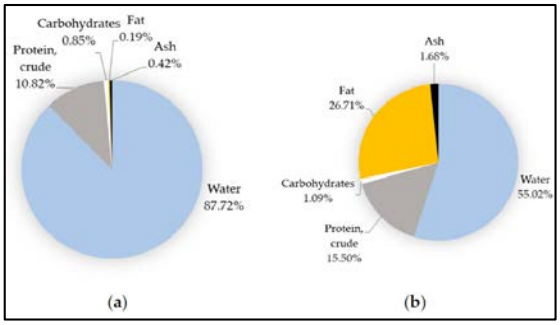

Fig 1: Basic composition of edible parts of the egg. (a) Egg white; (b) Egg yolk

The relative content of egg minerals, vitamins or specific fatty acids may vary from one national reference to another but remains globally comparable when considering major constituents such as water, proteins, lipids and carbohydrates. The major egg nutrients are, indeed, very stable and depend on the ratio of egg white to yolk in contrast to minor components, which are affected by several factors including hen nutrition. In a whole, raw and freshly laid egg, water, protein, fat, carbohydrates and ash represent about 76.1%, 12.6%, 9.5%, 0.7% and 1.1%, respectively (Godbert *et al*., 2019) [7].

3. Health benefits of chicken egg

There are several health benefits that can be derived from eggs, including:

- **Strong muscles:** The protein within eggs helps keep muscles working well while slowing the rate at which they are lost.
- **Brain health:** Eggs contain vitamins and minerals that are needed for the regular functioning of cells, including the brain, nervous system, memory and metabolism.
- **Good energy production:** Eggs contain all the daily vitamins and minerals that are needed to produce energy in all the cells of the body.
- **A healthy immune system:** Vitamin A, vitamin B_{12} and selenium are key nutrients to keeps the immune system healthy.
- **Lower risk of heart disease:** Choline plays an important part in breaking down the amino acid homocysteine, which is associated with the development of heart disease.
- **Healthful pregnancy:** Some nutrients within eggs help to prevent congenital disabilities.
- **Eyesight:** Lutein and zeaxanthin help to prevent macular degeneration, the leading cause of age-related blindness. Other vitamins also promote good vision.
- **Weight loss and maintenance:** The high quality of protein within eggs might help keep people energized and feeling full for longer. Feeling full prevents snacking, which reduces overall calorie intake.
- **Skin benefits:** Some vitamins and minerals within eggs help promote healthy skin and prevent the breakdown of body tissues. A strong immune system also contributes to a healthy look overall.
- The health benefits of eggs can only be experienced when they form part of a balanced diet.

Consumers have started viewing food from a radically different vantage point which has evolved into an exciting area of the food and nutrition sciences known as functional foods. Functional foods can be defined as those providing health benefits beyond basic nutrition and include whole, fortified, enriched or enhanced foods which have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis at effective levels. Eggs have been described as "Nature's original functional food" (Digambar *et al.*, 2018) [6].

Eggs are being used worldwide as food due to its protein quality (high biological value), low cost and palatability. In spite of all positives, it is being often blamed as high cholesterol food because of its lipid profile in the yolk. Due to this, a cholesterol phobia has been raised among the health cautious populations, which leads to a declining trend in egg consumption throughout the globe especially in western countries.

In the backdrop of above facts, the concept of "designer egg" has been evolved with aim to minimise the health negative nutrients (*viz*. cholesterol and triglycerides) and enriching it with health positive nutrients *viz*. ω-3 fatty acids and antioxidants, vitamins and minerals (Ankari *et al.,* 1998) [3]. "Designer eggs" are those in which the content has been modified from the standard egg (Bhat *et al.*, 2013) [4].

4. Demand of Designer Egg

- Foods are not intended to only satisfy hunger and to provide necessary nutrients for humans.
- Consumer demands have changed considerably in the last few decades.
- Consumers more and more believe that foods contribute directly to their health.
- Improve physical and mental well-being of the consumers.
- Increasing demand of functional foods in developed countries.
- Provides important export opportunities for developing countries.

5. History of Designer Eggs

Cruickshank (1934) [5] was one of the first researchers documented the ability to change the nutrient profile of the egg. In the late 80s, Sim, Jiang and their associates worked together to produce nutrient enriched eggs and developed designer egg rich in ω-3 fatty acids with antioxidants and patented this egg as 'Professor Sim's designer egg'. Later in 1997, Van Elswyk developed eggs enriched with conjugated linoleic acid (CLA). In Australia, Farell (1998) enriched the eggs with folic acid and iron. Other available designer eggs in the market include eggs enriched with vitamins. In Canada, Leeson and Caston, (2004) produced lutein and selenium enriched eggs which help in preventing eye disorders. In India, Narahari (2005) [14] 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 in herbal active principles like allicin, betaine, euginol, lumichrome, lumiflavin,, lutein, sulforaphane, taurine and many others, 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.

6. Egg Nutrients Can Be Manipulated For

- Cholesterol content
- Fatty acid profile: ω-3 fatty acids
- Vit. E, Vit. D & Folic acid
- Minerals – Fe, Zn, Se, I & Cr
- Carotenoids, lutein & Yolk colour
- Herbal enrichment

7. Ways to Produce Designer Eggs

- Inducing metabolic changes in the hen that can result in synthesis of compounds that essentially end up in the egg
- Changing the characteristics of membrane transport to facilitate movement of compounds into the egg
- Manipulating the diet of the hen such that the desired compounds level increase in the egg

When considering egg enrichment with nutrients, several factors need to be taken into account

- Efficiency of nutrient transfer from feed to the egg
- Availability of commercial sources of effective feed forms of the nutrient

- Possible toxic effects of nutrients for the laying hens (Vitamin A and D are toxic for chickens at high levels)
- Amount of nutrient delivered by an egg in comparison with Recommended Dietary Allowance (RDA)
- Established health promoting properties of nutrients and their shortage in a modern diet.
- Possible interactions with assimilation of other nutrients from the egg
- Stability during cooking
- Effect of nutrient enrichment on appearance and taste (Vitamin E, carotenoids and selenium do not affect egg taste but help prevent fishy taste in ω-3 eggs).

8. Various Types of Designer Eggs

8.1 Low Cholesterol Eggs

Egg is a cholesterol rich food. A large egg contains about 210 mg of cholesterol (Mahima *et al*., 2012) [10]. Assumptions like egg consumption will increase the serum cholesterol levels directly; many have reduced the egg consumption. This "cholesterol phobia" has scared the people in developed countries until 1990 and still continued to do so in developing countries including India, due to ignorance, leading to low egg consumption.

Even though the nutritional superiority of the egg has been proved beyond doubt, the egg consumption in India is very low due to vegetarianism as well as cholesterol scare. Although, the nutritionists and cardiologists have established that there is only an insignificant correlation between dietary and serum cholesterol levels; the consumers are still scared of consuming cholesterol rich foods, hence there is an urgent need to reduce the egg yolk cholesterol levels as well as to incorporate several other health promoting components in the egg. Genetic selection of hens for lowered cholesterol has not been successful in lowering the egg cholesterol content. Lowering egg cholesterol has centered mostly on diet and pharmacological intervention. The most effective way to lower egg cholesterol content is dietary manipulation of the hen.

High cholesterol leads to …

- Too much cholesterol can build up in arteries over time
- Leads to Atherosclerosis in vital arteries
- Cause heart attacks and strokes
- A major constituent of gallstone (Digambar *et al.,* 2018) [6]

Egg cholesterol levels are very difficult to influence by dietary manipulation, but some improvement has been reported from supplementing with Co and Cr. It has been reported that supplementation with dietary micro minerals (Co, Cr, Zn and I), vitamins (Vit. A, Vit. E and niacin), various oils and herbal plants may change the yolk cholesterol level (Muduli *et al.,* 2018) [12].

Iinfluence of designer diets enriched with ω-3 fatty acids and antioxidants from natural sources on egg yolk composition of 'white leghorn' hens reduced ($p<0.01$) the yolk cholesterol levels and increasing omega-3 fatty acid levels in the egg (Sujatha and Narahari, 2011) [20]. Another way of reducing the cholesterol concentration in yolk by supplementation of *Lactobacillus acidophilus* (LA). Addition of different amount of *Lactobacillus acidophilus* to ration of laying hens resulted in decrease yolk cholesterol (Alaqil *et al*., 2020) [1]. Supplementing the flaxseed meal or mixture with rapeseed meal or rice bran up to 10% of feed in the diet of poultry will help in reduction of yolk cholesterol (Panaite *et al*., 2020) [16].

8.2 ω-3 Enriched Eggs

Commercial table eggs contain a high proportion of ω-6 PUFA (mainly 18:2n-6) but are a poor source of ω-3 fatty acids (Bhat *et al.,* 2013) [4]. Attempts to produce eggs high in ω-3 PUFA can be divided into two groups. The simplest way is to produce an egg enriched in linolenic acid, which is a precursor of DHA and is also considered to have a protective effect against fatal ischemic heart disease.

Advantages of ω-3 fatty acid enriched eggs

Prevention of coronary heart disease, infant development, reduction of cancer and inflammatory disease, prevention of psychiatric disorders, helpful in improvement of oxygen supply to the tissues, increase in brain function, give relief in treatment of rheumatoid arthritis, improves skin and relieves arthritis and helpful in curing inflammatory disorders and improve immune responses (Surai and Sparks, 2001) [23].

For this purpose, the hen's diet is usually relatively rich in flaxseeds, soyabean, walnut, and oils -from canola, safflower and vegetable oils and Marine algae; as a result the egg's yolk is enriched with alphalinolenic acid (ALA) and the level of docosahexaenoic acid (DHA) is also enhanced. Among all the sources flaxseed oil is the richest source followed by fish and soybean oil. The second approach to enhance levels of n-3 in the egg, by including pre-formed DHA in the hen's diet, usually in the form of fish oil, is a more promising one. However, this may be associated with a pronounced fishy taste in the egg yolk.

Supplementation of marine algae (*Schizochytrium* spp.) at different levels from 1.27%, and 1.77% (Kostik *et al.,* 2015) [8] and 5% of an oil mixture, 0.5 mg organic selenium/kg, 200 mg lutein/kg and 200 mg vitamin E/kg (Kralik *et al.,* 2018) [9] as source of omega-3 fatty acids in the diet of layer bird resulted in eggs enriched with important ω-3 fatty acids (ALA, EPA and DHA) significantly.

8.3 Vitamin Enriched Eggs

Vitamins are essential nutrients found in foods. While their requirements are small, they perform specific and vital functions essential for health maintenance. The egg, and more precisely the egg yolk, is a vitamin-rich food that contains all vitamins except vitamin C (Ascorbic acid). The egg yolk contains high amount of vitamin A, D, E, K, B_1, B_2, B_5, B_6, B_9 and B_{12}, while egg white possesses high amounts of vitamins B_2, B_3 and B_5 as well as significant amounts of vitamins B_1, B_6, B_8, B_9 and B_{12}.

Nabor (1993) [13] reviewed the successful attempts to modify vitamin composition of eggs by dietary vitamin supplementation and concluded that egg vitamin content is highly variable and dependent primarily on the vitamin concentration of the hen's diet. Vitamin A content of eggs responds slowly to changes in dietary vitamin A content, whereas, the riboflavin content responds rapidly to dietary changes in dietary riboflavin concentration. Vitamin D, pantothenic acid, folic acid, biotin and B_{12} respond greatly to increases in the dietary levels of these vitamins.

Transfer efficiency to the egg is very high for vitamin A and high for riboflavin, pantothenic acid, biotin and B_{12}. Transfer efficiency is medium for vitamin D_3 and vitamin E and low for vitamin K, thiamin and folic acid. Vitamin content of eggs can be increased over certain ranges of diet fortification and with varying efficiency of vitamin transfer. If development of designer eggs containing higher concentrations of certain vitamins is ever the objective of a commercial enterprise,

vitamin transfer efficiency and vitamin cost would be two of the major considerations used in determining the economic feasibility of marketing such eggs.

Supplementation with vitamin E is generally recommended to stabilize egg lipids against rancidity and extend the shelf life of the product to layer birds. Proper vitamin nutrition has significant implications in gastrointestinal health of hens and this could have positive ramifications in marketing eggs with a higher vitamin level and better nutritive value (Zang *et al.*, 2011) [26]. Saleh *et al*. (2021) [18] reported that increased in egg-yolk vitamin E concentration and reduction in liver malondialdehyde (MDA) content by the treatment with the natural colorant could be attributed to the carotenoid content of red pepper paprika (*Capsicum annuum* L.), which has a well-known antioxidant function, such as vitamins C and E and vitamin A precursors.

8.4 Mineral Enriched Eggs

The shell contains majority of the minerals in an egg. There are approximately 2,200 mg of calcium and 20 mg of phosphorus in the shell. There has been very little success in changing the calcium and phosphorus content of the albumen and yolk. However, It is possible, to increase the content of chromium, selenium, iron, zinc, iodine and manganese. This has been done through dietary supplementation of the hen. These minerals are important in human health. Therefore, there has been some interest, in promoting these eggs as designer eggs (Bhat *et al.*, 2013) [4].

Eggs can be enriched with many types of minerals by supplementation in hens feed (Satapathy *et al*., 2017) [19]. This includes minerals like selenium, iodine, chromium and copper. These minerals are very important for our health, deficiency of which can lead to the emergence of various diseases.

The dietary supplementation of hens with zinc (zinc sulphate @ 75 mg/kg diet) is an effective approach to enrich egg with zinc (Megha *et al*., 2021) [11] and iodine @ 6.50 ppm in layers diet is economically better for the production of iodine enriched eggs followed by feed iodine supplementation @ 3.25 ppm (Sumaiya *et al.*, 2016) [22]. It is feasible to supply 50% of the RDA for selenium in one egg by supplementing the feed of the layer hen with 0.4 ppm selenium in the form of selenomethionine (Yaroshenko *et al*., 2003; Surai, 2000) [25, 24].

8.5 Antioxidants Enriched Eggs

In today's lifestyle, everyone has to experience a lot of stress. These stresses are mediated via oxidative processes which generate a lot of free radicals and peroxides inside the body. Dietary antioxidants are the best counter for such stresses. Designing the eggs with higher content of antioxidant is an added way out. Egg naturally contains antioxidant substances like vitamin E, vitamin A and selenium etc. But their levels are not sufficient to protected designer eggs rich in ω-3 FA (Digambar *et al*., 2018) [6].

Poultry eggs are rich sources of natural antioxidants like vitamin-E, Se, carotenoid pigments, flavonoid compounds, lecithin and phosvitin but at the same time, are highly susceptible to oxidative rancidity during storage. These antioxidants protect the fat-soluble vitamins and other yolk lipids from oxidative rancidity. The designer eggs, 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 (Muduli *et al*., 2018) [12].

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, catalaze constitute an integral part of antioxidant cellular enzyme system in ω-3 enriched products to reduce lipid peroxidation. The dietary supplementation of vitamin E is commonly used in commercial ω-3 enriched products to mitigate the oxidation of ω-3 FA, thereby preventing the formation of undesirable fishy flavor and warmed over flavor in refrigerated, cooked and raw meat. Besides these, other anti-oxidants as chemicals and herbs may be added, to prevent oxidative rancidity.

The advantages of enrichment of the egg with anti-oxidants include:

- Decreased susceptibility to lipid peroxidation.
- Prevention of fishy odour to the product.
- Good source of antioxidants in human diet.
- Prevents destruction of fat-soluble vitamins.
- Prevents denaturation of natural fat-soluble pigments.
- Promotes the overall health of the consumers.

8.6 Pigment Enriched Eggs

The color of the yolk is a reflection of its pigment content. In addition, the type of pigment in the egg and its concentration are directly influenced by the dietary concentration of any particular pigment. In many countries, deep yellow or orange colour yolks are preferred over pale yolks. Natural carotenoid pigments like carotenes, xanthophyll, cryptoxanthin, zeaxanthin, lutein present in alfalfa, corn gluten meal, blue green algae - spirulina, marigold petal meal and capsicum impart rich yellow and orange colors to the yolk. Some of the pigments are having vitamin A activity. Most of these natural pigment sources are used in feeds at 1-5 % levels to increase the yolk colour. The active pigments extracted from these sources are sufficient at 0.05 - 0.1 % level, to give the same level of pigmentation. Turmeric powder at 0.5 kg along with red chilli powder at 1 kg/tone of feed, not only improve the yolk colour, but also act as anti-microbial agents and anti-oxidants. Fat soluble azo dyes are also used for pigmentation, but this is banned in many countries.

The beneficial effects of pigment enrichment in the yolk include:

- It assists in preventing muscular degeneration.
- It is responsible for attractive colour of yolk.
- It acts as antioxidant and anti-carcinogenic agent.
- Lutein is responsible for safeguard to the retina.

Spirulina supplementation in functional feeds contributed to the rich orange yolk colour due to its high carotenoid pigment content (Sujatha and Narahari, 2011) [20]. Ross and Dominy (1990) [17] and Anderson *et al.* (1991) [2] also used spirulina in hens' diet to increase yolk colour. Sujatha *et al*. (2015) [21] showed with their studies result that the incorporation of marigold as a wholesome feed additive for desi birds under semi range system has beneficial effects on enrichment of caroteinoid pigments in egg yolk and improvement of color of desi chicken egg yolk that is most preferred by the health conscious consumers. Saleh *et al*. (2021) [18] concluded that egg-yolk color from hens fed the natural (paprika) colorant was more yellow than that produced from those fed the control diet. This is a significant contribution, particularly considering that egg-yolk color remains an essential criterion

for consumer choice. It is well known that the color of yolk is strongly and substantially correlated to the carotenoid content.

8.7 Herbal Enriched Eggs

Phytobiotics or plant-derived products containing several plant secondary metabolites can be used in poultry feed to improve the performance of hen and to produce herbal enriched super eggs. Chicken feed may be supplemented with herbs like garlic/onion leaves, spirulina, basil leaves, turmeric powder, citrus pulp, flaxseed, red pepper, fenugreek seeds etc. These super eggs show lower LDL cholesterol, immunomodulator property, antioxidant, anticarcinogenic properties, higher omega-3 fatty acids etc. (Muduli *et al*., 2018) [12].

All these indicated that the overall health promotion in hens as well as possible health promotion in humans is possible by popularizing herbal enriched eggs.

In India, Narahari *et al*. (2005) [14] has produced herbal enriched designer eggs (HEDE) which were not only rich in ω-3 FA but also had vitamin-E, Se, carotenoids, certain B-complex vitamins and trace minerals. These eggs were also rich in several herbal active principles like allicin, betaine, eugenol, lumiflavin, lutein, sulforaphane, taurine and a lot of more active principles depending on herb fed to hen. Examples of health-promoting components include garlic, fenugreek and bay leaves. Garlic (*Allium sativum*) has potential hypolipidemic, hypotensive, hypoglycemic, hypothrombotic, hypoatherogenic and galactogenic properties.

Table 1: Active ingredients present in herbal enriched designer eggs and effect on human health (Satapathy *et al*., 2017) [19]

Herbs	Principle Active Ingredients	Benefits
Garlic, onion and their leaves	Allicin, Allylic sulfide	Lower LDL cholesterol as well as anticarcinogenic properties
Spirulina, marigold petals, alfa-alfa, red pepper	Carotenoid pigments	Antioxidant and anticarcinogenic
Turmeric powder	Flavonoid components	Antimicrobial as well as antioxidant
Bay (curry) leaves, Marigold petals	Lutein	Antioxidant, Improve vision
Flax seed, canola fish, oil insects, worms	ω-3 PUFA	Decrease LDL cholesterol, hypertension, angina and atherosclerosis
Sugar beet, grape pulp	Betaine	Decrease plasma homocysyeine, which ruptures arterial walls
Fenugreek, spices	Quercitin, Luteolin, Diosgenin, citogenin	Stimulates insulin secretion, antimicrobial

9. Conclusion

Poultry eggs are 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 hen with the different available feed supplements in requisite amounts, value added and health promoting products 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.

10. Future Prospects

Designer eggs with new functional properties are highly demanding, however, still there is lack of knowhow for their commercial production. There is need for more research for commercial production and marketing of these new generation egg and egg products. Further, more research should be done in this area to improve designer egg quality and assess long-term effects of their consumption and ultimately to convince customers of the benefits of eating these eggs.

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