Designer Eggs: Revamping Nature's Perfect Package

Vidhu Kumar[1*], Shreya Mishra[2]
[1] Animal Nutrition Division, ICAR- National Dairy Research Institute, Karnal, India -132001
[2]Livestock Products Technology, ICAR-Indian Veterinary Research Institute, Izzatnagar, Bareilly, India-243122
[*]Corresponding author e-mail - www.kumarvidhu@gmail.com
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Abstract

Eggs are nutritionally dense functional foods containing high-quality protein, essential fatty acids, vitamins, minerals, and bioactive compounds. However, concerns over cholesterol and saturated fat have limited their consumption among health-conscious populations. Designer eggs—produced by modifying hen diets—offer a means to enrich or reduce specific nutrients, such as increasing omega-3 fatty acids, conjugated linoleic acid (CLA), vitamins (A, D, E), minerals (selenium, iodine, iron), and antioxidants, while lowering cholesterol and saturated fat levels. Dietary additives like fish oil, flaxseed, herbs, trace minerals (chromium, copper), and antioxidants can effectively alter egg yolk and albumen composition. Such modifications must be balanced to avoid off-flavours, maintain hen welfare, production efficiency, and product safety. Designer eggs represent an opportunity to meet the demands of health-conscious consumers, improve nutritional security, and possibly support premium markets, provided they are produced economically, safely, and transparently.

Keywords: Designer eggs, Nutritional enrichment, Omega-3 fatty acids, Cholesterol reduction, Vitamins and minerals fortification, Antioxidants, Egg quality, Diet manipulation in laying hens, Functional food, public health/consumer demand.

Introduction

Eggs have been hailed as "Nature's original functional food," containing thirteen essential vitamins and minerals (Hasler, 2000). The protein quality in eggs is often regarded as superior to many animal protein sources, and they are among the most affordable options for a high-quality nutritional package. A single large egg provides approximately 70-80 kcal of energy, 7g of protein, 4.5g of total fat, 1.5g of saturated fat, 0.5g of polyunsaturated fat, 2.0g of monounsaturated fat, 200-250mg of cholesterol, 65mg of sodium, 60mg of potassium, 1g of total carbohydrates, 300mg of choline, and significant amounts of vitamin B12, folic acid, selenium, riboflavin, vitamin D, phosphorus, vitamin E, and vitamin A. While eggs are nutritious and of high quality, their high cholesterol content can limit consumption. However, the cholesterol from eggs is significantly less than what the human body produces (Gilbert, 2000). Poultry egg and meat are being tailored to perform specific functions effectively and reliably to meet consumer needs and preferences. With self-sufficiency in food production, increased

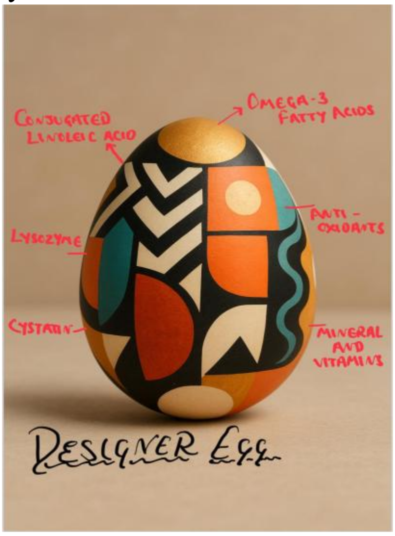

Fig: - Enrichment of Egg

consumer purchasing power, lifestyle changes, and demand for food with specific qualities or functional properties, has intensified in recent years. In an integrated production system, designer products can offer additional profits to producers if quality commands a premium price in the market. Although India still faces a quantitative supply deficit to meet poultry product demand, design aspects can be leveraged to enhance long-term market prospects. To meet the growing demands of health-conscious consumers, eggs are being designed, though only a small percentage are sold as designer eggs.

The possibilities for designing eggs are endless, including enhanced nutrition, value addition, and added processing. The nutrient content of free-range eggs is the same as conventional eggs if not subjected to different feeding regimens. Organic eggs are produced by hens raised under organic farming standards. Eggs from hens fed a completely vegetarian diet are generally termed vegetarian eggs, suitable for lacto-ovo-vegetarians. In a competitive market, those who successfully adapt remain successful. Enhancing consumer health and nutritional status by designing the nutritional profile of poultry eggs through dietary approaches is a relatively straightforward concept. Eggs can be designed through dietary approaches either through feed intrinsic factors, supplementation of specific nutrients or certain herbs or specific drugs.

Enrichment of Egg: Enrichment of chicken eggs with functional nutrients such as polyunsaturated fatty acids, conjugated linoleic acid, essential minerals, vitamins, and other bioactive compounds, along with strategies to reduce yolk cholesterol, represents a promising approach toward producing "designer eggs." These nutritionally enhanced eggs possess superior biological value and align with contemporary consumer demands for health-promoting and value-added animal-derived foods.

Omega-3 Fatty Acids: The fatty acid profile of a hen's diet is directly mirrored in the lipid composition of its egg yolk. Considerable research has focused on enriching eggs with omega-3 (n-3) fatty acids due to their well-documented benefits for cardiovascular health, inflammation control, and cancer prevention (Grashorn, 2005). Dietary inclusion of ingredients rich in linolenic and docosahexaenoic acids (DHA) can substantially elevate yolk concentrations of these compounds. Some designer eggs have been reported to contain up to 30-fold higher DHA levels compared with conventional eggs (Narahavi, 2003).

Such enriched products are marketed globally under various trade names, including *Omega Eggs* in Germany (Hartfiel et al., 1997), *Columbus Eggs* in the United Kingdom (De Meester et al., 2000), and *Bio-Omega-3 Eggs* in Greece (Yannakopoulos et al., 2004). Omega-3 polyunsaturated fatty acids (PUFA) have attracted growing interest among nutritionists and health experts for their protective effects against cardiovascular disorders, neural degeneration, and mood imbalances. DHA, in particular, is a critical structural component of the brain and retina, supporting cognitive development and visual acuity, while its deficiency has been linked with impaired neural and retinal function (Mellor, 2005).
Chicken eggs offer an efficient vehicle for delivering PUFA to humans, and numerous studies are exploring dietary strategies to modify yolk lipid composition. Typical enrichment sources include fish oil, linseed, sea algae, and certain cereals such as corn and oats. Marine algae are regarded as the most effective source, producing more stable and bioactive omega-3 forms than those from plant oils. However, inclusion of fish oil above minimal levels can impart undesirable off-flavours. Combining animal (fish) and vegetable oils, such as rapeseed or linseed, has proven useful. Because PUFA enrichment increases yolk susceptibility to oxidation, concurrent supplementation with antioxidants like α-tocopherol (vitamin E) is recommended to maintain product quality.

Conjugated Linoleic Acid (CLA)

Conjugated linoleic acids (CLA) are naturally occurring derivatives of linoleic acid found in animal-based foods. Over the past two decades, extensive research in experimental models has highlighted their potential health-promoting roles, including the reduction of carcinogenesis, atherosclerosis, and plasma cholesterol, along with immunomodulatory effects (Aletor et al., 2003). Although milk and dairy products are the primary dietary sources of CLA for humans, eggs can also be enriched with these fatty acids through the inclusion of specialised oil formulations containing CLA in poultry diets (Du et al., 2001).

Nutrient enrichment in eggs has been shown to enhance human plasma nutrient status significantly. Surai et al. (2002) reported that daily consumption of designer eggs enriched with vitamin E, carotenoids, selenium, and DHA for eight weeks markedly elevated plasma concentrations of α-tocopherol, lutein, and DHA in human volunteers. Similarly, Farrell (1991) observed that subjects consuming omega-3–enriched eggs for 22 weeks exhibited increased blood levels of EPA, DHA, total omega-3 fatty acids, and HDL cholesterol, without any rise in total cholesterol or triglycerides.

Further supporting evidence was provided by Vishwanathan et al. (2009), who demonstrated that consuming two to four egg yolks daily for five weeks improved macular pigment optical density in older adults with low baseline levels, while also increasing serum HDL cholesterol. Importantly, LDL cholesterol remained unchanged. Significant elevations in serum zeaxanthin (up to 82%) and moderate increases in lutein were also recorded, suggesting that nutrient-enriched eggs can contribute meaningfully to ocular and cardiovascular health without adverse lipid effects.

Antioxidants

α-Tocopherol (vitamin E) is a potent antioxidant that is readily deposited into the egg yolk when included in poultry diets (Galobart et al., 2001). Other yolk constituents such as selenium and carotenoids also contribute to oxidative stability (Yaroshenko et al., 2004). The deposition of these antioxidants occurs in proportion to their dietary supply, allowing flexible enrichment without compromising egg quality. While elevated carotenoid levels intensify yolk pigmentation, their supplementation must maintain the manufacturer's recommended ratio of yellow to red pigments to avoid undesirable coloration (Galobart et al., 2001). Artificial carotenoids may also be used for enrichment.

Selenium enrichment requires greater care, as excessive dietary intake poses toxicity risks to humans. However, it is feasible to produce eggs containing approximately 35 µg of selenium per egg, which accounts for nearly half of the human recommended daily intake (Yaroshenko et al., 2004). Importantly, enrichment with selenium, carotenoids, or α-tocopherol has shown no detrimental impact on the sensory or functional properties of eggs.

Because polyunsaturated fatty acids (PUFA) increase oxidative susceptibility, omega-3–enriched eggs are more prone to lipid oxidation and off-flavors (Tserveni-Gousi et al., 2004). Off-flavors are particularly associated with lower-grade fish oils; hence, only high-quality sources should be used along with adequate α-tocopherol supplementation to stabilize yolk lipids (Galobart et al., 1999). Overall, omega-3 enrichment does not adversely affect other quality attributes of the egg.

In parallel, growing consumer concern over cholesterol and saturated fat intake has driven the development of low-cholesterol or modified-fat eggs. Several dietary interventions—such as the inclusion of fiber, garlic, ginger, copper, and omega-3 fatty acids—have successfully reduced yolk cholesterol by up to 30%. Herbal additives like *Guggul*, *Terminalia arjuna*, cinnamon, and *Amla* have been reported to lower yolk cholesterol by 14–20% after several weeks of feeding (Sharma et al., 2009). Experimental formulations combining atorvastatin, niacin, and ethylenediaminetetraacetic acid (EDTA) achieved reductions of up to 35%. Similarly, dietary supplementation with copper (300 mg/kg) and chromium (3200 µg/kg) has proven effective in producing low-cholesterol eggs.

In addition to these functional improvements, eggs are valuable natural sources of lutein and zeaxanthin—carotenoids highly bioavailable from egg yolks (Handelman et al., 1999). These compounds are concentrated in the macula and play a vital role in protecting against age-related macular degeneration and early atherosclerotic changes (Dwyer et al., 2001). Increased intake of lutein through eggs or green leafy vegetables may help slow the progression of arterial lesions and support ocular and cardiovascular health.

Enhancement of Lysozyme and Cystatin Content in Eggs

Lysozyme and cystatin are key antimicrobial proteins present in egg albumen, playing a crucial role in protecting the developing embryo from microbial invasion. Unlike yolk components that can be influenced through diet, the composition and levels of albumen proteins cannot be altered directly via feed, as their synthesis occurs in the magnum of the oviduct and is regulated by the hen's genetic and RNA coding mechanisms (Trziszka et al., 2002).

The albumen contains several biologically active proteins exhibiting antimicrobial and antiviral properties, with lysozyme and cystatin being the most notable. Additionally, immunoglobulin Y (IgY) contributes to the egg's defensive capacity. Enhancement of these proteins can be achieved by immunostimulation of hens through vaccination with agents such as sheep red blood cells (SRBC) or other immune challenges, which stimulate higher production of immune-related proteins in eggs (Sim et al., 2000).

Genetic variation among hen breeds also influences lysozyme and cystatin content, suggesting potential for selective breeding programs to enhance the concentration and activity of these beneficial proteins. However, it is important to consider possible implications for egg quality and consumer health, as certain egg white proteins, including lysozyme, may elicit allergic responses in sensitive individuals (Mine, 2003).

Enrichment of Eggs with Minerals and Vitamins

The nutritional profile of eggs can be effectively enhanced through strategic dietary interventions in laying hens. Modern consumer demand has shifted toward functional foods, leading to the availability of eggs that contain reduced cholesterol and saturated fats, while being enriched with beneficial components such as vitamin E, omega-3 fatty acids, and essential minerals.

Mineral Fortification

Mineral content in eggs can be influenced significantly by dietary supplementation. Chromium-enriched diets have been shown to increase chromium levels in both yolk and albumen, with concentrations peaking at nearly tenfold higher than baseline within the first two weeks of supplementation before stabilizing at two- to threefold levels thereafter (Kang et al., 1996). Similar findings reported a fivefold increase in chromium content upon dietary inclusion, although prolonged supplementation beyond 30 days led to a gradual decline (Meluzzi et al., 1996).

Eggs are naturally rich in **iron**, providing about 1 mg per standard egg, making them a valuable dietary source for individuals requiring high iron intake with controlled caloric consumption. Iron enrichment, both from inorganic and organic sources, can elevate yolk iron levels by 125%–140% (Biehl et al., 1997). Moreover, co-supplementation of vitamin A enhances the absorption and utilization of iron, suggesting synergistic fortification benefits.

Zinc enrichment also holds nutritional promise. Increasing dietary zinc to 80 mg/kg in a basal diet of 65 mg/kg doubled yolk zinc content from 0.84 to 1.62 mg/egg (Naber & Squires, 1991). In contrast, **manganese supplementation** shows limited response, with only marginal increases in yolk manganese levels, while excessive Mn can interfere with iron absorption (Baker & Halpin, 1991).

Dietary inclusion of **iodine sources** such as potassium iodide, kelp, or iodized linseed meal significantly elevates egg iodine content up to 400 µg/egg, a tenfold increase over basal levels (Naber & Squires, 1991). Similarly, iodine supplementation at 2.6 mg/kg produced eggs containing 74 µg iodine per egg compared with 26 µg in regular eggs (Ternes & Leitsch, 1997). **Selenium enrichment** is another vital approach, with different selenium sources showing distinct tissue distribution patterns. Selenium-methionine increases selenium levels mainly in the albumen, whereas sodium selenite and selenium-cysteine are more effective in enhancing yolk selenium content. Supplementation can increase total egg selenium concentration up to fivefold, from 2 to 10 µg/kg (Latshaw & Osman, 1975), providing a reliable means of selenium delivery to humans.

Vitamin Fortification

Fortification of eggs with vitamins D, E, and folic acid represents a growing innovation in functional food development. The **liver acts as a major reservoir for vitamin A**, causing yolk concentrations to rise gradually in response to dietary increases. Over a supplementation range of 2600–22,000 IU/kg diet, liver vitamin A stores rose nearly 200-fold, while yolk levels doubled, reflecting the regulatory nature of hepatic vitamin A storage (Naber, 1979).

Vitamin D is efficiently transferred to the yolk, with concentrations reaching 14.5 IU/g when hens consumed diets containing 20 IU/g (Kawazoe et al., 1996). **Vitamin E** enrichment follows a dose-dependent pattern, peaking after three weeks of supplementation before stabilizing at half its maximal value by the seventh week (Surai et al., 1997). Such eggs provide a valuable dietary source of vitamin E and exhibit improved oxidative stability, especially when fortified simultaneously with omega-3 PUFAs to prevent lipid peroxidation.

Dietary supplementation with **biotin** increases its concentration primarily in the albumen, while yolk levels remain stable, demonstrating a positive linear relationship with dietary intake (Robel, 1991). Similarly, **folic acid enrichment** leads to yolk folate concentrations 43 times higher than in hen plasma, making eggs an excellent dietary source to prevent folate deficiency, especially during pregnancy (Sherwood et al., 1993).

Riboflavin deposition in both yolk and albumen increases nearly linearly with dietary supplementation, reaching half-maximal levels at 2 mg/kg feed (White et al., 1986). Yolk riboflavin accumulation depends on riboflavin-binding proteins, while albumen levels are limited by other transport factors. Increasing dietary riboflavin to 2–4 times the hen's requirement can enhance riboflavin deposition up to threefold (Squires & Naber, 1993).

Therapeutic Potential of Egg-Derived Antibodies (IgY)

The oral administration of antibodies has emerged as a promising approach for disease prevention, offering a viable alternative to traditional vaccination and antibiotic therapy. Unlike antibiotics, this method poses no risk of developing microbial resistance. In this context, **avian immunoglobulin Y (IgY)**—extracted from egg yolk—has gained significant attention due to its ease of production, cost-effectiveness, and ethical advantages over mammalian antibodies (IgG). Hens can produce large quantities of IgY without invasive procedures, and egg collection provides a non-stressful, sustainable method for antibody harvesting. Furthermore, avian IgY exhibits minimal cross-reactivity with mammalian immune components, making it suitable for oral immunotherapy applications.

Functionally, IgY retains its **antigen-binding capacity and bacterial agglutination properties** even after exposure to moderate heat (15 minutes), digestion by intestinal proteases, and multiple freeze–thaw or lyophilization cycles. Given its stability and scalability, egg yolk–derived γ-globulin shows potential as a **functional food additive** to enhance the safety and shelf-life of food products (Stefaniak & Kopec, 1997).

Experimental studies have demonstrated the **broad antibacterial activity** of yolk IgY against various human gastrointestinal pathogens such as *Escherichia coli*, *Klebsiella pneumoniae*, *Salmonella enteritidis*, and *S. typhimurium*, with no significant loss of antibody activity even after refrigeration for up to three weeks. The feasibility of producing disease-specific IgY-enriched eggs underscores their potential application in both **human and veterinary medicine** for passive immunization and disease control.

Notably, antibodies produced in hens immunized against *Streptococcus mutans* significantly **inhibited bacterial adherence** compared to control groups (Hamada et al., 1991; Otake et al., 1991). Clinical investigations further revealed that **mouth rinses containing anti-*S. mutans* IgY** effectively prevented the colonization of this cariogenic bacterium in humans (Hatta et al., 1997), suggesting a novel oral preventive strategy for dental caries.

Additionally, antibodies targeting **interferon-γ (IFN-γ)** have shown promise in modulating immune and inflammatory responses in experimental models of autoimmune disorders, cancer, graft rejection, and delayed-type hypersensitivity. These findings highlight the therapeutic potential of **egg-derived anti–IFN-γ IgY** as a cost-effective alternative to monoclonal antibody therapies generated via recombinant DNA technology.

Safe Egg Production through Nutritional and Microbial Interventions

Microbial contamination of eggs primarily originates from intestinal colonisation of *Salmonella*, *Campylobacter*, and *Coliform* bacteria in poultry. These pathogens are major contributors to foodborne illnesses such as gastroenteritis in humans, posing significant public health and food safety concerns. Therefore, strategies that limit intestinal colonisation in chickens can effectively reduce the risk of contamination in both eggs and poultry carcasses.

Recent research highlights the potential of **nutritional manipulation and microbial modulation** in improving egg and meat safety. Supplementation with beneficial microbes—such as *Bacillus subtilis* C-3102—has been shown to markedly lower intestinal counts of *Salmonella* and *Campylobacter* in broilers (Maruta et al., 1996). Similarly, broilers fed **probiotic-enriched diets** exhibited significantly reduced bacterial loads of *Salmonella*, *Campylobacter*, and total aerobic counts compared to control birds (Fritts et al., 2000).

In addition to probiotics, **prebiotic supplementation** has demonstrated comparable efficacy in improving intestinal health and lowering pathogen load. Diets enriched with prebiotics led to reduced populations of *Campylobacter* and *Coliforms* in poultry carcasses (Khaksefidi & Rahimi, 2005). Furthermore, both prebiotic feeding regimes and optimised fasting durations before slaughter have been reported to influence microbial load and enhance meat safety (Mandal et al., 2005; Elangovan et al., 2004).

Conclusion: Designer eggs represent a powerful tool for improving nutritional health and meeting consumer demand. Through relatively simple modifications of hen diets—adding omega-3 sources, trace minerals, vitamins, antioxidants, herbs, and reducing cholesterol-increasing components—it's possible to produce eggs with improved fatty acid profiles, higher levels of micronutrients, and lower saturated fat and cholesterol. However, success depends on maintaining flavour and quality (avoiding off-flavours or oxidation), ensuring hen welfare and production efficiency, managing costs, and guaranteeing food safety. If these factors are balanced, designer eggs can contribute to improved public health, increased market opportunities for producers, and potential alleviation of micronutrient deficiencies.

Competing Interests:

The authors declare that they don't have any competing interests.

References:

Baker, D. H., & Halpin, K. M. (1991). Interaction of manganese and iron in laying hens. *Poultry Science*, 70, 1212–1219.

Elangovan, A. V., Mandal, A. B., Tyagi, P. K., et al. (2004). Influence of dietary prebiotics and fasting duration on meat microbial quality in broilers. *British PoultryScience*,45,94–101.

Farrell, D. J. (1998). Enrichment of hen eggs with n-3 long-chain fatty acids and evaluation of enriched eggs in humans. *The American Journal of Clinical Nutrition, 68*(3), 538–544.

Fraeye, I., De Smet, S., & Bruneel, C. (2012). Dietary enrichment of eggs with omega-3 fatty acids: A review. *Animal Feed Science and Technology, 171*(3–4), 74–90.

Hasler, C. M. (2000). The changing face of functional foods. *Journal of the American College of Nutrition, 19*(suppl. 5), 499S–506S.

Kelly, E. R., et al. (2014). The effect of modified eggs and an egg-yolk based beverage on macular pigment and serum carotenoids: randomized intervention. *PLOS ONE, 9*(4): e92659.

Lewis, N. M., Seburg, S., & Flanagan, N. L. (2000). Enriched eggs as a source of n-3 polyunsaturated fatty acids for humans. *Poultry Science, 79*(7), 971–974.

Raes, K., De Smet, S., & Demeyer, D. (2002). The deposition of conjugated linoleic acids in eggs of laying hens fed different fat sources. *The Journal of Nutrition, 132*(11), 2978S–2981S .

Singh, V. P., & Sachan, N. (2010). Designer eggs: A smart approach for health-conscious persons. *Poultry Planner, 11*, 21–23.

Surai, P. F., MacPherson, A., Speake, B. K., Sparks, N. H. C., & Cram, E. (2000). Designer egg evaluation in a controlled trial. *European Journal of Clinical Nutrition, 54*, 298–305.

Trziszka, T., Smietana, Z., & Polowska, E. (2002). Biological activity of egg white proteins. *Food Chemistry and Function*.