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An Updated Review on Chicken Eggs: Production, Consumption, Management Aspects and Nutritional Benefits to Human Health

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Abstract

Ancestors of the modern chicken were domesticated from members of the Gallus genus probably 7 to 8 thousand years ago in southeastern Asia. Subsequently, they spread globally for meat and egg production. In the chicken egg, there is a balance of numerous, high-quality nutrients, many of which are highly bioavailable. The egg confers a multitude of health benefits to consumers emphasizing its classification as a functional food. Current global per capita egg consumption estimates approach 9 kg annually but vary greatly on a regional basis. This review deals with global production, consumption, and management aspects such as hygiene, feeding, and housing. Management aspects play key roles in the composition, quality, food safety, and visual (consumer) appeal of the egg. Also the manipulation of egg nutrients and value for human health is discussed.

Keywords

Chicken Eggs, Production, Consumption, Nutrient Manipulation, Egg Quality, Bioavailability, Health Benefits

1. Chicken Eggs—An Overview

Worldwide cosmopolitan chicken egg production and consumption have shown remarkable, broad and comprehensive dynamics over the past two decades. Updated scientific based information is documented here by the author on the chicken egg, its management aspects and benefits to human health.

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2. Egg Producing Chicken—History and Origin

Chickens and man have coexisted for several millennia. Humans keep chickens primarily as a source of food, consuming both their meat and eggs. Chickens (*Gallus domesticus*) possess a long history, and showing variations while tracing its origin. Its use for food was evident during the Roman Empire which is credited with the development of breeds, especially for egg production [1]. Chicken breeds with novel traits were developed during the first half of the 19th century for exhibitions throughout Europe [2]. Some breeds have contributed to those used in current chicken production.

Molecular studies involving phylogenetic analyses revealed that domestic chickens originated from the red jungle fowl whose ancestors in turn originated from the green jungle fowl, *Gallus varius*. DNA sequences of chickens, red and green jungle fowls formed reciprocally monophyletic clusters [3]. *Gallus* species establish the red jungle fowl as the major progenitor to the domestic chicken with minor infusions of grey jungle fowl, *Gallus sonneratii* and of Ceylon jungle fowl, *Gallus lafayetti* [4] [5]. Whereas DNA based studies of clades (groups possessing a common ancestor) revealed separate domestications throughout southwest China, and southern and southeast Asia [6] [7].

China appears to have been the introduction of chickens to surrounding areas. Chickens were kept and also traded by the Harappan culture in the Indus valley as early as 2500-2100 BC, and in parts of Africa around 2000 BC [8]. Around 1000 BC the chicken spread in an easterly direction from Asia through Polynesia and beyond [9]. However, recently researchers [10] attribute a later origin of the chicken in South America and some Polynesian sites to early Spanish explorers. According to this study, among Polynesian chickens, one particular cluster of mitochondrial DNA (Haplogroup D) represents the founding lineage of these chickens. Haplogroup E is the key piece of genetic evidence supporting the pre-Columbian presence of Polynesian chickens on the coast of South America, Easter Island and coastal Chile [11]. Other haplogroups (A, B and E) are existed worldwide. Research study also reported arrival of chickens into Micronesia from New Guinea about 3850 years ago, and later to Solomons, Vanuatu and eastward [11] [12]. Overall spread of the domestic chicken occurred over the millennia.

3. Development of Management Systems

More than 50 billion chickens are raised annually as a source of food, for both their meat eggs. Chickens raised for eggs are usually called layers while chickens raised for meat are often called broilers [13]. On average a laying hen produces one egg/day. All laying hens start to lay exactly when they are 21 weeks old. Planning is therefore required for egg production to be constant so as to meet market demand. In areas where the climate is hot and humid, commercial hybrid laying hens produce on average between 180 and 200 eggs/year. In more temperate climates laying hen can produce on average between 250 and 300 eggs/year.

Wild chickens meet their needs naturally, however chicken domestication has introduced new environments and restrictions. Management systems have evolved and become extensive. Confinement facilitates egg collection, chicken capture, reproduction, protection from predators/pests and biosecurity measures. Chickens that are partially or totally confined, require man to provide those needs which cannot be accommodated naturally such as: provision of water and feed; shelter and/or ventilation; artificial lighting; cleaning and/or disinfection of facilities. These needs become more intensive and critical as the space/hen is reduced and production increases. Confinement systems include: on range in fields/paddocks where climate permits; confined indoors in pens with access to range; confined totally indoors either in pens or cages with either single or multiple hens/cage. The relative performance of hens from 18 to 76 weeks of age in conventional cages, in enriched cages and in pens revealed only small differences in egg production, mortality and feed/egg [14]. Globally, a range of relevant management systems is applied. The specific type is determined largely by climatic and economic restraints.

Modern poultry production occurs primarily in enclosed buildings to protect the birds from weather, predators, and the spread of diseases from wild birds. This has allowed farmers to greatly increase production efficiency while significantly reducing the amount of labor required. The majority of egg production is carried out using a conventional cage system, where layers live in cages and have limited mobility. Housing density and reduced space per hen have aroused consumer concern about hen welfare. In this perspective management systems have developed to meet the chicken's needs for health and safety. These usually include: provision of water and feed; shelter and/or ventilation; artificial lighting; cleaning and/or disinfection of facilities. This also happened in response to worldwide research and development activities about welfare-friendly poultry housing system and husbandry [15]-[18] as well as in compliance to a European Union Council Directive (1999/74/EC) on welfare of laying hens. This directive requires conventional laying cages to be phased out by 2012 [19]. Traditional cages have been modified and "enriched" cages and aviaries have been developed and encouraged along with free- range systems. The benefits of free-range poultry farming for laying hens include opportunities for natural behaviors such as pecking, scratching, foraging and exercise outdoors [20]. However the production costs of these modified measures are much higher than those of eggs from caged hens [21] [22].

Layer operation size in developed countries has increased dramatically during the last century. Flocks of 100,000 laying hens are common with some exceeding 1 million [23]. Large layer farms consist of several large houses of in-line and off-line types [18]. In in-line production systems, eggs from all houses are gathered and transferred to an adjacent plant for processing and refrigeration prior to shipping.

The appropriate **nutrition** provision to hen is pre-requisite for optimal egg production. Nutritionists design rations to meet the laying hen's energy, protein, minerals and vitamins requirements determined by maintenance, body weight and level of egg production [24]. Ingredient selection is determined by availability, price and, if available, nutrient biological availability estimates, to minimize cost of the ration. Specific fats and cereal grains provide energy, content and digestibility of essential amino acids determine the protein source, a variety of vitamins and trace minerals are included in supplements given to egg laying hens. The laying hen requires higher levels of calcium and vitamins A, D and choline than other chicken. Hens can be sustained on diets with limited nutrients; however, production levels will be reduced accordingly.

To meet consumer demands, **"organic eggs"** are now produced. Hens producing organic eggs has specific housing requirements as outlined by the European Commission Regulation (EC) No 889/2008. This poultry farming must be kept in a free range system and fed only organic feed free of antibiotics and synthetic fertilizers. Hen's feed must include grains from only crops certified as "organic". Antibiotics can be used but only for the control disease outbreaks. Laying hens must have free access to the outdoors with adequate vegetation during the daytime [25] [26].

Family poultry production has provided opportunities for income generation to the local communities, apart from satisfying their own needs. This production system is promoted in Ghana, Tanzania, and Zambia by the Food and Agriculture Organization of the United Nations and the International Egg Commission. Recommendations to improve management and production for these smaller and indigenous operations are made available [27] [28].

Worldwide active research activities are on record with the objective to improve poultry practices with emphasis on housing systems [29]-[35]. In the same perspectives symposia, with the intervals of four years, were periodically held in number of European countries (Denmark, 1981; Germany, 1985; France, 1989; UK, 1993; Netherland, 1997; Switzerland 2001; Poland, 2005 and Italy, 2009) to address the poultry farming systems and related issues. Latest and updated research based contributions on this subject gathered at the 9th European symposium on poultry welfare held in Uppsala, Sweden [36]. This meeting illustrated extensive research efforts made in number of countries by evaluating welfare of hens including housing and husbandry research and development to disseminate information all across the world.

4. Global Production and Consumption of Eggs

Global egg production, consumption and their effects on human health, and use as functional foods is expanding owing to their capacity to decrease the risks of some diseases, apart from easy availability and affordability. In both developed and developing countries an increased egg production and consumption could significantly improve nutritional needs of a common man and children with developing or growing minds. Eggs are an economical source of nutrients for a healthy diet and life, especially important for the mental development of growing children [28] [37] [38]. A brief overview of production and consumption of egg is given as under:

4.1. Production

In 2012, about 21.2 billion chickens (accounted for over 90% of global egg production) were located in: Asia, 12.0; America, 5.28; Europe, 2.01; Africa, 1.79; Oceana, 0.13 [39]. Total shell egg production was 66.4 million tonnes in 2012 [39] with 57.8% provided by only 5 countries (**Table 1**).

Annual egg production has increased 2.3% globally from 2000 to 2010, although the regions varied [39]. The United Nations' Food and Agriculture Organization projects a production of 70.4 million tonnes of eggs in 2015

Table 1. The world's top egg producing countries for the year 2012[a].

Country	Egg production (tonne)[b]	World total (%)[c]
China, mainland	24,500,000	36.9
United States	5,435,168	8.2
India	3,600,000	5.4
Japan	2,506,768	3.8
Mexico	2,318,261	3.5

[a]Food and Agriculture Organization of the United Nations: Statistics Division (FAOSTAT), 2014. Production: Livestock Primary: Eggs Primary, http://faostat3.fao.org/home/E (accessed January, 2015 [39]). [b]One tonne = 1000 kg. [c]Total egg production worldwide in 2012 was 66,373,179 tonnes.

and 89 million in 2030. A major proportion of the increase will come from developing countries. China, the world's top egg producer, reportedly produced 23.9 million metric tons of eggs in 2011, and produced an estimated 28.3 million metric tons of eggs in 2012 Currently China holds about 45% of the world's total production of eggs. Based on FAO data and China's projected 2% percent compound annual growth rate, the country will produce 34.2 million metric tons of eggs by 2020 and 39 million by 2030 [40].

In 2010, just five countries of Americas—the US, Mexico, Brazil, Columbia and Argentina—produced some 10.8 million tons of eggs or 84% of the regional total. In 2012 US egg production is slightly higher than in 2011. Egg production in the US is expressed in millions of dozens, with the latest estimate for 2012 at 7700 million dozen. However forecast for 2013 points to a fall of 1% to around 7610 million dozen due to higher feed costs. US Department of Agriculture long-term projections foresee growth in US production as total output rises from 7610 million dozen in 2013 to 8043 million dozen in 2021. Canada's egg industry has expanded by about 1.5% a year [41].

India is the third-largest egg-producing country followed by Japan, the fourth largest producer. However Japan recorded a decrease in tonnes of eggs produced in 2011 and 2012 as the number of layers and layer farms in that country decreases.

In European Union countries, the ban in 2012 imposed on use of conventional cages [19] appears to have restricted growth since 2008 to 1% annually associated with the increased production costs. In 2012, growth actually declined in the European Union as noted by a decrease in tonnes of eggs produced. The region's largest egg producers remain France and Spain, followed by Italy, Germany, the Netherlands and the UK [39]. This has provided an opportunity to the egg producers across Asia and America to fulfill the demand-supply vacuum created in the European Union member countries. Two other egg producing countries, Brazil and Russia, have shown marked increases in production since 2008 with expected increases during 2012.

4.2. Consumption

Eggs are an inexpensive source of high-quality protein, essential vitamins, and minerals that are needed for a healthy diet and a healthy life. By 2050, the world's population is expected to reach 9 billion people, with the highest population growth rates occurring in regions suffering most from food insecurity. The International Egg Commission's vision is to facilitate an independent and sustainable food supply, ensuring food self-sufficiency for people now and in the future [37]. Global egg consumption has tripled in the past 40 years with consumer quality expectations increasing just as rapidly [42]. The middle class population can afford to buy eggs for consumption across major Asian nations such as China and India. This led to constant increase in the per capita consumption of eggs. Since the population in the region is high and on the rise, the smallest rise in the per capita consumption would trigger a significant upswing in the retail egg market and demand. Overall, world countries vary largely in egg consumption levels. Annual consumption of eggs determined largely by the country's wealth, ranges from 300 g/person in African countries to 19.1 kg in Japan. Only 9 of 43 sub-Saharan African countries have an average consumption higher than 2 kg while most Asian and American people eat at least twice that amount [28]. Consumption of eggs in Canada went from 22.0 dozens/capita in 1980 to 17.1 dozens/capita in 1995. But a slow gradual increase in consumption started in 1996 due to a variety of factors including the introduction of designer eggs with omega-3 fatty acids and reached 20.5 dozens/capita in 2012 [43]. With undernutrition remaining a significant problem in many parts of the developing world, eggs may be regarded as part of the solution to make up malnutrition [44].

5. Chicken Egg Components

The egg consists of a yolk at the centre, surrounded by albumen, both enclosed within the shell. The formation and development of the yolk occurs in the hen's left ovary. Following ovulation, egg formation continues in the left oviduct where the albumen and later the shell are deposited. The detailed structure is illustrated in **Figure 1**.

The shell, albumen and yolk make up 9% - 12%, 60% and 30% - 32% of the egg respectively. Respective total solids of the albumen and yolk are 11% - 12% and 50% - 52%. Albumen or egg white comprised of 90 % water and 10% protein. Inside the yolk is the germ cell (or germinal disc). This is the site of cell division if the egg is fertile. The colour of the yolk varies (light yellow or intense yellow etc.) depending upon the laying hen's diet. However the colour of the yolk has no connection with nutritive value of an egg. The shell is 94% calcium carbonate crystals. The porous structure is semi-permeable limiting the passage of air and water. Variability in egg shell color is due to hen's genetics. Shells are more commonly white or brown, but may be blue or green. Color influences regional consumer demand but does not influence egg quality or taste [45].

Several membranes keep egg components organized. An outer shell coating, the cuticle, helps to exclude bacteria and dust. Inner and outer egg shell membranes separating the shell and albumen are transparent protein membranes that provide an efficient defense against bacterial invasion as well as a foundation base for shell formation. The air cell forms, between the outer and inner membranes at the egg's blunt end, as the egg contents cool and contract after oviposition. Air cells grow larger with age. The chalazae, opaque ropes of egg white, hold the yolk in the center of the egg and attach the yolk's casing to the membrane lining the shell. The vitelline membrane, a transparent barrier enclosing the yolk, prevents leakage of yolk contents into the albumen.

Egg composition is relatively consistent in terms of total protein, essential amino acids, total lipid, phospholipids, phosphorus, and iron. Other components such as fatty acid composition, mineral contents, vitamins, carotenoids, antioxidants, and cholesterol content are influenced by the diet of the hen and are more variable. These Component percentage differences may be attributable to strain, age, and environmental conditions [46]. Due to the decline in some egg proportions as the hen ages, flocks are replaced after 1 production cycle by younger flocks to avoid such differences [47]. However, molting tends to restore egg proportions of aged hens [48]. Proper production methods also tend to reduce this variation in components and facilitate egg marketing. Generally hen's age, genetics, environment and feed quality especially manipulated with added nutrients play a role in determining egg quality and its healthy nutrients composition.

6. Nutritional Values and Importance for Human Health

Hen's egg is a cosmopolitan functional food. It is not only part and parcel of breakfast time but also predominantly consumed with any meal or as snack. There are range of delicacies all around the world which include

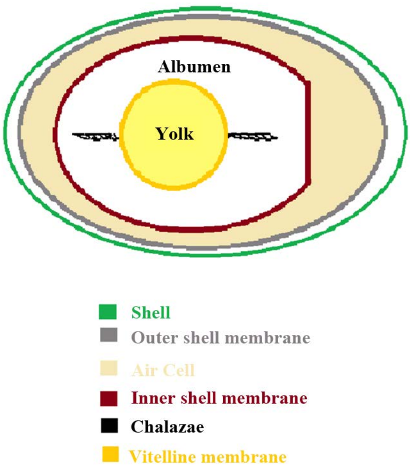

Figure 1. Chicken egg components.

Chinese, Japanese, Indian, European, Portuguese, African, Latin American and North Americans egg dishes.

Eggs, commonly available and low in cost or more affordable, represent a "complete food" required for well-being and are recognized by consumers as versatile and wholesome with a balance of essential nutrients to sustain both life and growth [44] [49] [50]. The mother's feeding is believed to influence infant health but later upon introduction of solid foods eggs are important source of protein and nutrients [51]. In addition to their nutritional value, eggs have health promoting properties. Many are preventative in nature, others have therapeutic potential. In short, eggs are an inexpensive and low-calorie source of high-quality protein and other nutrients beneficial to human health, details of which are as follows;

- Egg proteins, about 6.5 g/egg, contain a balanced supply of the 9 amino acids essential to human health: histidine; isoleucine; leucine; lysine; methionine; phenylalanine; threonine; tryptophan; valine [52]. Protein quality, a measure of the efficiency of use of the consumed protein by the human body, is determined by the presence and proportions of these amino acids of the protein. The protein quality of eggs is high, 91% if cooked [53] and is the standard for evaluating other foods [54]. Amino acids are vital for production of enzymes, some hormones, hormone receptors, DNA components, and other functional components required for growth, tissue maintenance, and regulation of metabolic functions.
- The polyunsaturated fatty acids, alpha-linolenic acid (n-3) and linoleic acid (n-6) are essential to human health. Eggs contain about 70 mg of omega-3 (n-3) fatty acids. Linoleic acids are metabolized to arachidonic acid; alpha-linolenic acid to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) [54] [55]. These essential long-chain fatty acids are components of phospholipids which contribute flexibility to cell walls and reduce plasma cholesterol levels [56]. The EPA and DHA also appear to reduce risks of cardiovascular, central nervous system, and mental health diseases, inflammation, and immune infections [55]. In addition, they have preventive and therapeutic roles for other chronic diseases.
- Egg contains fat soluble vitamins; A, D, E, and K, and water soluble B vitamins; thiamine (B1), riboflavin (B2), pantothenic acid (B5), pyridoxine (B6), biotin (B7), folate (B9), cobalamine (B12), and choline. Levels of B2 and B12 are relatively high; levels of B5, B9, A, and D are moderate. Adequate maternal folate levels reduce the risk of neural tube defects in new-born infants [57]. It also contains the minerals calcium, iron, magnesium, phosphorus, selenium, sodium, and zinc.
- Egg contains about 200 mg of cholesterol. This has suppressed egg consumption in the past [58]; however, cholesterol has many important functions in the human body. Functional roles of cholesterol in steroid hormones, vitamin D, precursor for bile to digest and absorb fat etc. is already established in human studies Negative impression about cholesterol is now faded away The body needs to achieve a balance when it comes to cholesterol consumption. It is now established that there is no association between egg consumption and risk of cardiovascular disease [59]. With the exception of familial hypercholesterolemia subjects [60], consumption of 1 egg/day does not increase serum cholesterol and risk of cardiovascular disease among healthy men and women [59].
- Positive associations between oxidative stress and the incidence of chronic diseases such as cancers and heart diseases have been reported [61]. Eggs contain several antioxidants which reduce free radicals arising from cellular metabolism. These antioxidants include: i) selenium which acts to reduce the oxidative stress from free radicals promoting heart disease [62]; ii) carotenoids in egg yolk (such as lutein and zeaxanthin) play a role in the prevention of cataracts and age-related macular degeneration [63]; iii) vitamin E reduces the oxidation of fats in low-density lipoprotein improving cholesterol transportation and balance with decreased risk of heart attack and death from heart disease [62].
- Hen's egg is a good source of antibodies like "IgY"; better than mammalian immunoglobulin "IgG". In a 6-week period, a hen produces about 298 mg of specific antibodies ("IgY"), compared with only 17 mg from a rabbit. These immunoglobulin antibodies are important egg constituents, with high nutritional value, may help to relief human discomforts from viral and bacterial infections. Proteins in the egg white as lysozyme, ovotransferrin, and avidin have proven to exert numerous biological activities [64]-[66].

7. Manipulation of Egg Nutrients—"Designer Egg"

The internal components of the egg can easily be transformed by simple procedures like mixing of added nutrients to hen's feed. Worldwide different egg producing companies are selling modified or enriched eggs with different brand names. In all those brands proper labelling of enriched egg nutrients need to be clearly mentioned for the consumer's satisfaction.

Eggs from hens on range have omega-3 fatty acid levels six fold [67] higher than those from caged hens. This reflects that eggs may differ in their nutrient content based on how the hens were raised and fed. Some components of the egg can be transformed by fortifying the hen's diet to enrich the egg [50]. These include the polyunsaturated essential fatty acids, the carotenoids (lutein, zeaxanthin, and lycopene), vitamins, and minerals.

Omega-3 fatty acid levels in eggs can be elevated by feeding canola oil, soybean oil, flaxseed, walnut, spinach and mustard greens which are rich sources of omega-3 fatty acids. Generally supplementation of omega-3 fatty acids with food may decrease the risk of heart diseases by 50% - 70% [68], and other health related issues. Conjugated linoleic acids, not normally present in the egg, can be established by dietary supplementation of hens [69]. Soybean oil enriched with stearidonic acid (SDA) may be used in place of flaxseed oil in laying hen's feed. Using flax seed soil, the desaturation of α-linolenic acid (ALA) and docosahexaenoic acid (DHA) is considered to be slowest for the hepatic conversion of ALA to eicosapentaenoic acid (EPA) and DHA. Whereas soybean oil enriched with SDA reported to be readily incorporated into adipose tissue than into egg yolk, and as such more efficiently enriches eggs with very long-chain n-3 polyunsaturated fatty acids [70]. This suggests an alternate pathway for the hepatic secretion and transport of SDA in the laying hen. Physiological benefits of some conjugated linoleic acids in animals include an anti-carcinogenic effect, enhancements of immune function along with reductions in inflammation, catabolic effects of immune stimulation, asthma, arteriosclerosis, diabetes symptoms, and hypertension [71]. More information on the relative roles of n-3 fatty acids and conjugated linoleic acids is required as a basis for recommendations involving conjugated linoleic acids fortification of egg.

Enrichment of hen's feed with carotenoids such as canthoxanthin and lycopenes and sources such as marigold, chilly or corn can enrich the egg carotenoids and intensify the yellow color of yolk [72]. By feeding tomato pulp to hens, eggs can also be fortified with lycopenes from a natural source [73]. Supplementing the hen's diet with vitamins A, D, and E can increase yolk contents up to 10 fold. High concentrations of polyunsaturated fatty acids in the yolk enhance the antioxidant effect of vitamin E [74] [75]. Dietary sources can increase the egg content of the water soluble vitamins B2, B12, B1, biotin, folic acid, and pantothenic acid. Many minerals, especially selenium and iron, may also be incorporated.

The above changes appeal to the consumers' desire for "healthier" or value added eggs. Nutrient fortified and "designer" eggs may be marketed with appropriate labels provided the label meets with egg marketing regulations of that region. Such nutritional manipulation in hen's feed is for value addition of eggs nutrient, and is well documented in worldwide scientific literature [50] [65] [66] [70] [74] [76]-[83]. Moreover this manipulation free from any harmful components or chemicals. Having reviewed the relevant scientific literature it is concluded that "designer eggs" can be considered as a new type of functional food, enabling producers to provide a more diversified product thereby increasing product demand.

8. Awareness to Ensure Food Safety of Eggs

Eggs are one of nature's most nutritious and economical foods. To avoid contamination and food poisoning special care is needed with handling and preparing fresh eggs or egg products; frozen, liquid or dried egg products for consumption, as per the guidelines of USDA [84]. But before that proper practices in egg production and processing must be followed to avoid potential foodborne consumer illnesses. These illnesses may arise from either chemical (toxicants) or microbial contamination of eggs. Producers must ensure that the product marketed complies with the regulations governing the safety of food products. Among other things, it requires them to adopt preventive measures and to use refrigeration during egg storage and transportation.

Chemical contaminants originate from residues of either intended treatments involving veterinary drugs or feed additives, or inadvertent contaminants of environmental origin such as dioxins, furans, and polychlorobiphenyls [85]. Treatments with drugs and feed additives are regulated according to the toxicity of the drug and its potency based on maximum residue limits, treatment, and the withdrawal periods. All products during the medication and withdrawal periods are unfit for human consumption and must be discarded. Some drugs are banned and must not be used in food animal production. There are safe drugs that do not require withdrawal periods when used for food animals. In addition, hens may consume contaminated soil, feed, or water. These toxicants are often pesticides applied on crops and soils.

Microbial contaminants of eggs are usually enteric bacteria, *Salmonella enteritidis* being the greatest threat. Egg contents are often suitable media for bacterial growth. Hence, risk of egg contamination by pathogenic bacteria, especially *S. enteritidis*, is a major concern for egg production and egg product manufacturing industries

[86]. The "Code of Hygienic Practice for Eggs and Egg Products (CAC/RCP 15—1976)", adopted in 1976, revised in 2007, recommends practices for primary production, sorting, grading, storage, transport, processing, and distribution of eggs for human consumption. Overall this document deals with key aspects of hygiene in controlling and preventing contamination of eggs and egg products [87]. Measures taken to avoid contamination of the hens include: the selection of breeding stocks for pathogen resistance; maintain a pathogen-free status in parental flocks; use systems and procedures that prevent cracked eggs; decontaminate facilities between flocks; vaccinate hens against pathogens; use pathogen-free feeds and feedstuffs; maintain pest-free facilities; facilitate gastric microbiota development to enhance passive immunity; maintain facilities favoring clean egg production. Those measures to maintain pathogen-free eggs include: collect and cool as soon as possible and maintain in cool, clean storage; clean soiled eggs; if possible, pasteurize contaminated eggs. Having said that consumers are advised to buy eggs that have been refrigerated, clean and not cracked before processing/cooking. Especially pregnant women, babies, older adults and people with weakened immune systems should use egg products with caution [51] [84] [88].

9. Maintenance of Raw Egg Quality

Evaluation of the external and internal quality of chicken eggs is important. Egg quality defines those characteristics of an egg that affect consumer acceptability and preference. The quality of the egg, once it is laid, cannot be improved any further, however its maintenance is possible and mostly a preventive process. Once laid, quick egg collection and rapid storage in the cool room can minimize egg quality problems.

The component proportions for fresh egg are 32% yolk, 58% albumen and 10% shell [89]. Exterior and interior egg quality parameters includes shell cleanliness, shell soundness, shell texture, shell shape, relative viscosity of the albumen, shape and firmness of the yolk. Eggs are graded on the basis of these parameters. In many countries, shell eggs are graded by weight to enhance egg size uniformity [90] [91].

Exterior or the shell of each egg should be smooth, clean and free of cracks to avoid penetration by microorganisms, as per the guidelines set by USDA [90]. There are 5 major classes of shell defects: integrity, texture, shape, colour, cleanliness [92].

Interior egg quality, most important to consumers, begins to decline as soon as the egg is laid and has 3 components: yolk quality; albumen quality; overall quality. Egg yolk from a newly laid egg is round and firm. Rapid gathering and cooling of eggs and refrigerated storage at appropriate temperature and humidity can keep this feature intact. As the egg ages, the air cell grows larger; the yolk size increases due to water absorption from egg white, and resultantly looks flat and shows spots [89].

Over all egg quality is influenced by several factors including rearing, temperature, humidity, handling, storage, and egg age [93]-[95]. Hen's feed may also play a crucial role in maintaining the quality of eggs. The hens have an ability to obtain and deposit calcium. For example calcium is absorbed from the feed in the intestine of hen. An egg has an average of 2.3 g of calcium in the shell, and almost 25 mg in the yolk. A modern hen laying 330 eggs/cycle, and deposit 767 g of calcium [96].

Many egg defects are seldom seen by the consumer because defective eggs are detected either before or at grading and are rejected. Moreover, proper housing systems and feed management, egg storage and egg handling, together with selection efforts by poultry breeders can possibly reduce their incidence to low levels.

10. Conclusions

In recent decades, there has been an increasing demand for functional foods, which is expected to continue to increase in the future, owing to their capacity to decrease the risks of some diseases. Given the global importance of chicken eggs as a functional food having recognised nutritional significance, health beneficial effects of nutrients; mass production and consumption patterns are the clear reflection of ongoing positive and beneficial outcomes willingly availed by the consumers. To meet global demand by 2030, as much as 89 million tonnes of eggs will be required. The recurring question throughout the international egg industry, is, how to increase egg production sufficiently to feed the world's growing population, while also complying with increased regulations. Management aspects including hygiene, feeding, and housing play key roles in the composition, quality, food safety, and visual (consumer) appeal of the egg. For treating and controlling microbial infections in eggs, the use of antimicrobial agents is in practice. The proper use of antimicrobials must depend on the knowledge of interrelationships between bacteria, antimicrobial, host and consumer. Generally optimal selection of drug, dose and duration of antimicrobial treatment, along with a reduction in inappropriate and excessive use may help to reduce the chances of antimicrobial resistance.

Further the ability to enrich eggs with the vital nutrients, such as polyunsaturated fatty acids, the carotenoids (lutein, zeaxanthin, and lycopene), vitamins and minerals has provided egg producers with a unique opportunity to produce an innovative, premium quality and value-added product for the domestic and export markets.

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