



NUTRITIONAL COMPOSITION, BIOACTIVE COMPOUNDS AND HEALTH EFFECTS OF EGGS: A COMPREHENSIVE REVIEW

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Abstract: Eggs represent a nutrient rich food system that combines a balanced nutritional composition with a diverse range of bioactive substances that contribute positively to human health. This paper provides a thorough overview of the main constituents of eggs, including proteins, lipids, vitamins, minerals, and carotenoids, and summarizes their biological activities and functional properties. Proteins present in eggs, such as ovalbumin, ovotransferrin, and lysozyme, are known for their antimicrobial, antioxidant, and immune-regulating activities. In addition, phospholipids and choline from the egg yolk play crucial roles in maintaining cardiovascular and neurological functions. Lutein and zeaxanthin from egg yolk are highly bioavailable carotenoids with proven benefits for ocular and cognitive health. Additionally, the paper analyzes the potential role of egg intake in body weight regulation, cardiometabolic health, neurocognitive performance, bone integrity, and applications in sports nutrition. Evidence from epidemiological and clinical studies indicates that moderate egg consumption supports satiety, promotes muscle protein synthesis, and maintains lipid homeostasis without increasing cardiovascular risk. Overall, eggs qualify as functional foods due to their nutrient density and the synergistic action of their bioactive compounds, supporting health promotion and disease prevention across the lifespan.

Keywords: eggs, functional foods, bioactive compounds, cardiometabolic health, lutein and zeaxanthin, choline

1. Introduction

In the present context, foods should fulfill consumer preferences, ensure an adequate supply of essential nutrients, assist in the prevention of nutrition-related disorders, and enhance overall wellbeing. A good diet adequate for growth, development and maintenance of health is based on variety. This variety must supply human organisms with enough nutrients [1]. Access to sufficient food of adequate quality is essential to maintain normal body function throughout the life cycle [2]. Dietary habits in developed countries are commonly marked by excessive energy, saturated fatty acids, n-6 polyunsaturated fatty acids, and salt intake, together with a deficiency in n-3 polyunsaturated fatty acids, antioxidants,

and dietary fiber [3]. These facts are an important reason for the increasing number of people that suffer from obesity, cardiovascular diseases and chronic illness [4]. To improve public health, the World Health Organization [2] established dietary recommendations for fat consumption. These guidelines indicate that total fat intake should represent 15–30% of total dietary energy, while saturated fatty acids should not exceed 10% of caloric intake. Furthermore, the recommended proportions are 5–8% for n-6 polyunsaturated fatty acids, 1–2% for n-3 polyunsaturated fatty acids, and 10–15% for monounsaturated fatty acids [5]. Consequently, the nutritional profile of foods plays a significant role in consumers' food selection, contributing to a

growing demand for healthier dietary options [1]. Functional foods can be obtained by changing their composition through inclusion of certain ingredients beneficial to health or by modifying the quantity of certain components [6].

Eggs may be regarded as functional foods due to their valuable nutrient composition. They are rich in fatty acids and fat-soluble compounds, contain highly bioavailable carotenoids such as lutein and zeaxanthin, and represent an important dietary source of choline [7]. Eggs are excellent sources of selenium, vitamins D and E, and their proteins are characterized by high quality due to their composition in essential amino acids [1].

Eggs are an inexpensive food that provides vitamins, minerals, low carbohydrates, lipids, and proteins. They are a source of several bioactive compounds with documented biological activities, such as antimicrobial, antioxidant, immunomodulatory, anticancer, and antihypertensive effects [8]. In terms of structural composition, an egg is made up of about two-thirds albumen and one-third yolk [7].

2. Egg composition

2.1 Macronutrients

2.1.1. Egg proteins

From a structural perspective, an egg is made up of three principal elements: the shell, the egg white (albumen), and the yolk. The whole egg contains approximately 13% protein, whereas egg white and egg yolk contain about 11% and 17.5% protein, respectively. Several egg proteins, including ovalbumin, ovotransferrin, lysozyme, ovomucoid, ovomucin, and immunoglobulin Y, possess important biological properties [9].

2.1.2. Egg white proteins

Ovalbumin is the major protein from egg white and constitutes about 54% of the egg albumen. Ovalbumin is part of serine protease inhibitors and is a phosphorylated

glycoprotein [10]. It shows resistance to trypsin digestion in its native form; however, following heat treatment or exposure to acidic conditions or pH modifications, it becomes susceptible to trypsin hydrolysis [11]. In egg albumen, ovalbumin represents approximately 540 g/kg of the dry matter, has an isoelectric point of 4.5, a molecular weight of about 45 kDa, and a denaturation temperature of around 84 °C [12]. Ovalbumin represents the main allergenic component of egg white [13].

Approximately 12% of the proteins in egg white are represented by ovotransferrin, a monomeric glycoprotein that plays a role in the transport of ferric ions [14]. Ovotransferrin is a member of the transferrin protein family and represents approximately 120 g/kg of the dry matter of egg albumen. It has an isoelectric point of 4.5, a molecular weight of about 45 kDa, and a denaturation temperature of around 61 °C. Its capacity to bind iron is closely associated with its antimicrobial activity. [12]. Each molecule of **ovotransferrin** can bind two Fe³⁺ ions [15]. Lysozyme is a glycoprotein that accounts for approximately 3.5% of the proteins found in egg white and is composed of 129 amino acids. It represents about 34 g/kg of the dry matter of albumen and is characterized by an isoelectric point of 10.7, a molecular weight of approximately 14.3 kDa, and a denaturation temperature of around 75 °C [16]. Compared with lysozyme present in other food sources, egg-derived lysozyme exhibits greater solubility and stability [17]. In addition, it has the capacity to interact with negatively charged proteins such as ovalbumin, ovomucin, and ovotransferrin [18].

Ovomucoid is another glycoprotein present in egg white, representing around 11% of the total egg white proteins. This protein is heat resistant and acts as a trypsin inhibitor. It has a molecular weight of approximately 28 kDa, constitutes about 110 g/kg of the

dry albumen fraction, and is characterized by an isoelectric point of 4.1 and a denaturation temperature of about 77 °C [16]. It is also recognized as one of the major allergenic proteins found in egg white.

Ovomucin is a glycosulfoprotein that gives the gel-like structure of the eggwhite. It consists of approximately 2% of total proteins of egg white and its molecules are very large and contain sulphate esters, cystine and sialic acid activity [12]. Ovomucin is responsible for thinning egg white during prolonged storage, it has emulsifying and foaming properties [19]. The physicochemical properties of ovomucin are: 35 g/kg dry weight of albumen, the isoelectric point varies between 4.5-5.0 and the molecular weight ranges between 5500 and 8300 kDa [16].

In addition to the major proteins, egg white contains smaller quantities of other proteins, such as ovoglobulin, cystatin, avidin, and ovoflavin, which play important roles in determining the physicochemical and structural properties of the egg [19].

Ovoglobulin represents approximately 4% of the total proteins found in egg white. It is highly soluble in both high- and low-ionic-strength salt solutions and undergoes coagulation when exposed to heat. Additionally, ovoglobulin contributes to the foaming properties of egg white. Their isoelectric point ranges from 4.8-5.8, the molecular weights vary between 30 and 45 kDa and their dry weight in albumen is approximately 40 g/kg [16].

Cystatin is a cysteine proteinase inhibitor that exhibits antimicrobial activity against various pathogens and plays a role in preventing the degradation of the bone matrix [20]. This protein has a molecular weight of approximately 12.7 kDa, an isoelectric point of 5.1, and represents about 0.5 g/kg of the dry matter of egg albumen [21]. Avidin is a water-soluble glycoprotein with a strong affinity for biotin; binding with this vitamin reduces its biological

availability [22]. Biotin is a water-soluble vitamin, and a single avidin molecule is capable of binding up to four biotin molecules [23,24]. Biotin has an important role in fatty acids synthesis and amino acid catabolism. Human organism cannot synthesize biotin and therefore it must be obtained from exogenous sources [22]. Avidin is about 0.05-0.5% of egg white proteins [25]. It has a high isoelectric point of 10 and a molecular weight of approximately 68.3 kDa [16]. Ovoflavin is a riboflavin-binding protein which is present in both egg white and yolk in similar quantities. It contains high selenium quantities that other egg proteins [26].

2.1.3. Egg yolk proteins

Egg yolk is composed of plasma (approximately 80% of the yolk) and granules. Proteins account for approximately 23% of the dry matter of the egg yolk plasma fraction and are mainly represented by low-density lipoproteins and globular glycoproteins [27]. Yolk granules contain high quantities of lipids (33%) and proteins (53%) compared to plasma [28]. Low-density lipoprotein from yolk plasma contains triglycerides and cholesterol in their structure [29]. High-density lipoproteins are composed of protein, lipids, cholesterol and other minor lipids [30].

2.1.4. Lipids

Eggs are considered a rich source of phospholipids; a single large egg contains around 1.3 g of these lipids, which are mainly present in the yolk [31]. These phospholipids are represented by glycerophospholipid phosphatidylcholine, phosphatidylethanolamine, lysophosphatidylcholine, phosphatidylinositol, and sphingolipid sphingomyelin [32]. In general, phospholipids contain long-chain saturated and monounsaturated fatty acids [33]. Egg yolk lipids are organized as lipoproteins with a triglyceride and cholesteryl ester core, surrounded by phospholipids, cholesterol, and embedded apoproteins,

with total lipid content largely fixed and fatty acid composition strongly influenced by hen diet. Compared to many other foods of animal origin, egg yolk is characterized by a higher proportion of unsaturated fatty acids relative to saturated fatty acids. It also provides considerable amounts of essential fatty acids, including linoleic acid, while containing only small quantities of cholesterol-raising saturated fatty acids such as myristic acid [34].

2.1.5. Carbohydrates

Eggs contain minimal carbohydrates (approximately 0.7%) and no dietary fiber, with glucose as the predominant free sugar, mainly concentrated in the egg white. Trace amounts of other sugars, including fructose, lactose, maltose, and galactose, are also present in both yolk and white. Additionally, many egg proteins are glycoproteins, undergoing post-translational glycosylation during formation of yolk, membranes, and egg white [34].

2.2 Micronutrients

2.2.1. Choline in eggs

Choline is recognized as an essential nutrient because of its key roles in growth and development, the formation of membrane phospholipids, and the maintenance of normal neurological functions [35]. Choline and choline-related compounds like phosphocholine, lecithin, glycerophosphocholine and sphingomyelin are found in different foods. Eggs are a good source of choline and it is found in the egg yolk in the form of phosphatidylcholine [34]. Studies indicate that a large egg contains approximately 164 mg of choline, which represents about 30% of the recommended daily intake for men and 40% for women [36]. Although, small amounts of choline are produced by the liver, however, it has to be obtained through the diet in order to avoid deficiencies [37].

2.2.2. Vitamins

Eggs are an important source of several vitamins, including vitamins A, D, E, K,

B1, B2, B9, and B12. Fat-soluble vitamins are mainly located in the yolk, while water-soluble vitamins are primarily found in the albumen [38].

2.2.3. Minerals

Eggs represent an important source of essential minerals, notably phosphorus, calcium, and potassium, while also supplying moderate amounts of sodium. In addition, they contain several essential trace elements, including copper, iron, magnesium, manganese, selenium, and zinc.

The yolk is considered the main contributor of iron and zinc within the egg. From a nutritional perspective, these minerals are particularly important, as deficiencies in zinc, magnesium, and selenium have been associated with symptoms such as fatigue, depression, and various pathological conditions [34]. Moreover, the concentration of certain trace elements, such as selenium and iodine, can be significantly affected by the diet of the laying hens [34].

3. Bioactive compounds

3.1. Lutein and zeaxanthin in eggs

Lutein and zeaxanthin are carotenoids that represent a group of lipid-soluble bioactive compounds. Since they cannot be synthesized in vivo, they must be obtained through the diet [39].

The content of lutein and zeaxanthin in eggs is relatively low compared to the content in vegetables (spinach, broccoli, kale), but they are highly bioavailable. These carotenoids are fat soluble, mainly deposit in the yolk [40] and their content is influenced by the hen's diet [41]. Egg consumption has been associated with the formation of larger low-density lipoprotein (LDL) and high-density lipoprotein (HDL) particles, which may enhance cholesterol transport [32]. Egg yolks contain approximately 1282 µg/100 g lutein and 640 µg/100 g zeaxanthin [42]. Lutein and zeaxanthin have several biological effects

Table 1

Lutein and zeaxanthin content in whole egg and egg yolk

Product	Lutein (μg/100 g dry matter)	Zeaxanthin (μg/100 g dry matter)	References
Egg yolk	116.8 - 2477.7	121.8 - 1287.5	[43]
Egg yolk	787	762	[44]
Egg yolk	1490	3100	[45]
Egg yolk	709 - 1072	709 - 1594	[46]
Egg (yolk + white)	288	279	[44]
Egg (yolk + white)	640 - 1530	670 - 960	[47]
Egg (yolk + white)	1200	1140	[48]

on humans like antioxidants, vitamin A precursors and protein binding agents [41]. Various studies have highlighted the role of lutein and zeaxanthin in supporting ocular health [49], preventing age-related macular degeneration [50], and reducing the risk of cardiovascular diseases, stroke, and cancer [51]. These carotenoids have also been associated with protective effects against neurodegenerative disorders [52] and beneficial effects on skin health [53].

4. Cholesterol

Eggs are an important dietary source of cholesterol, with a large egg containing approximately 186 mg, primarily located in the yolk [54]. Egg yolks from different bird species vary in fatty acid composition and cholesterol content, with mono- and polyunsaturated fatty acids, particularly n-3 and n-6 PUFAs, being abundant and physiologically desirable. Quail eggs exhibited the most favorable n-6/n-3 ratio (5.6:1), whereas ostrich and duck eggs had higher total fat and cholesterol levels [34]. Overall, quail eggs are characterized by lower cholesterol compared to other bird eggs, highlighting species-specific differences that are relevant for human nutrition [55].

5. Health effects of egg consumption

5.1. Appetite control and body weight regulation

Obesity represents a major public health concern and is associated with an increased risk of several chronic diseases such as hypertension, type 2 diabetes, coronary

heart disease, and osteoarthritis [56]. Although, multiple factors contribute to its development; excessive energy intake and insufficient physical activity are considered the primary causes. Consequently, regulating energy intake is essential for maintaining healthy body weight. Highly satiating foods could be used for body weight control. Eggs are an important source of macro- and micronutrients. Their high-quality proteins, which provide all essential amino acids, are considered the main contributors to the satiating effect of eggs by promoting appetite control and reducing subsequent energy intake. Eggs also contain bioactive compounds such as lutein and choline that contribute to their nutritional value [57]. Thus, eggs could be an ideal food to be included in diets in order to reduce obesity.

A study conducted on thirty obese women demonstrated that an egg-based breakfast, compared with an isocaloric bagel breakfast, resulted in greater satiety and significantly reduced short-term food intake [58]. In a study that involved 50 overweight or obese adults, the subjects received one of two breakfasts, either with egg or cereals. Subjects eating eggs had a lower energy intake in comparison to eating a cereal breakfast (both breakfasts containing the same energy) [59].

A crossover study evaluated the effects of isocaloric lunches consisting of eggs (omelette), jacket potato, and a chicken sandwich on satiety in 31 healthy male and

female participants. Energy intake was monitored over a four-week period. The egg-based lunch demonstrated a greater satiating effect compared with the jacket potato meal, suggesting that consuming eggs at lunch may enhance satiety more effectively than carbohydrate-rich meals and may help reduce energy intake between meals [56]. In a study involving 30 healthy non-smokers aged 19–50 years, participants consumed two isoenergetic breakfasts: an egg-based breakfast and a dough-pie breakfast. The high-protein breakfast, which provided 51% of total energy from protein, produced greater satiety than the comparison breakfast, which provided only 10% of total energy from protein. The satiating effect of the high-protein meal was associated with increased postprandial concentrations of glucagon-like peptide-1 (GLP-1), peptide YY (PYY), and other metabolites involved in appetite regulation [60]. The effects of albumin on appetite regulation and energy intake were compared with those of other protein sources, including whey, tuna, and turkey, in a crossover study involving 22 lean and healthy men. The results indicated that meals containing whey protein produced the lowest hunger ratings compared with the other protein sources. Tuna-based meals elicited the second-highest insulin response, which was associated with a significant reduction in appetite and subsequent food intake compared with meals containing turkey or egg proteins [61].

In a study conducted on 40 children between 8 and 10 years of age, the impact of three types of breakfast (egg, cereal, and oatmeal) on appetite and subsequent energy intake was assessed. Compared with an isocaloric cereal-based breakfast, the egg-based breakfast significantly decreased energy intake at lunch. However, while egg consumption reduced short-term energy intake, it did not affect longer-term intake, and appetite ratings remained unchanged. [62]. The effects of breakfast types (egg or

non-egg breakfast) on body weight were assessed on 73 freshman university students, aged 17–20 for a period of 14 weeks. During the study, a mean weight change of 0.73 ± 2.41 kg was observed but there was no significant interaction effect observed between breakfast type and weight or percentage of body fat [63].

A study including 152 overweight or obese but otherwise healthy adults aged 25–60 years investigated the effects of egg-based and bagel-based diets on weight loss. Participants were assigned to four groups: egg, egg diet, bagel, or bagel diet. After eight weeks, the egg diet group demonstrated significantly greater improvements than the bagel diet group, with a 61% larger reduction in body mass index, 65% greater weight loss, 34% greater decrease in waist circumference, and 16% greater reduction in body fat percentage [64].

In a randomized trial on 160 healthy overweight or obese subjects, the effect of egg or egg diet breakfast on weight loss was compared to bagel or a bagel diet. The two egg groups received an egg breakfast containing 2 eggs and the two bagel groups were given a breakfast equal in kcal and weight but containing bagels for more than 5 weeks. After 8 weeks, egg diet group recorded a greater weight loss (65%) compared to bagel diet group and 83% greater reduction in waist circumference. Weight loss induced by egg diet was about twice as the one induced by bagel breakfast. Egg breakfast consumption, while on weight loss diet, enhanced weight loss due to greater satiety [65].

5.2. Cardiometabolic health

The concept of cardiometabolic health encompasses both cardiovascular and metabolic disorders, including type 2 diabetes and metabolic syndrome. Cardiovascular diseases are recognized as the primary cause of death, especially among elderly individuals [66, 67]. Several conditions, including myocardial infarction,

stroke, heart failure, coronary artery disease, atrial fibrillation, and chronic kidney disease, are closely linked to type 2 diabetes and the development of atherosclerosis [68].

A 12-week study evaluated the effects of an eucaloric high-protein diet containing three whole eggs per day compared with a normal-protein diet without egg in 22 overweight adults aged 65–75 years. Over the course of the intervention, concentrations of insulin-like growth factor-1 increased independently of the diet, with a slight tendency toward higher levels in the egg diet group. However, no significant changes were observed in fasting glucose, insulin concentrations, or other cardiometabolic health markers [69]. The association between egg intake and the risk of cardiovascular disease, type 2 diabetes, and mortality was examined using data from the Caerphilly Perspective Cohort Study and the National Diet and Nutrition Survey. The Caerphilly study included 2,512 men aged 45–59 years, whereas the National Diet and Nutrition Survey comprised 754 adults aged 19–64 years. In men free of cardiovascular disease, egg consumption was not linked to an increased risk of cardiovascular disease, mortality, or type 2 diabetes. Furthermore, no associations were identified between egg intake and the incidence of myocardial infarction or stroke. Nevertheless, in individuals with type 2 diabetes or impaired glucose tolerance, egg consumption was associated with higher blood glucose concentrations [70].

In a study of 9,734 adults aged 25–74 years, the relationship between egg intake and the risk of cardiovascular diseases was evaluated. Participants were grouped based on their weekly egg consumption: none or less than one egg, 1–6 eggs, and more than 6 eggs per week. The findings showed no significant differences in the occurrence of stroke, ischemic stroke, or coronary artery disease between individuals consuming

more than six eggs weekly and those consuming none or less than one egg per week. Nevertheless, among participants with diabetes, higher egg consumption (more than six eggs per week) was associated with an increased risk of coronary artery disease [71].

A health examinee study using Western Australian adults (aged 15–88 years, a total of 514 subjects, 256 women and 258 men) showed that coronary heart disease risk increased with eggs consumption more than twice per week [72].

A cohort study involving 21,275 individuals investigated the association between egg intake and the risk of heart failure. Consumption of eggs up to six times per week was not linked to a higher risk of heart failure, whereas intake exceeding seven eggs per week was associated with an increased risk. These findings indicate that moderate egg consumption is not related to the development of heart failure [73].

Fourteen thousand one hundred and fifty-three (14,153) adults aged 45–64 years participated in an observational cohort study designed to evaluate the association between heart failure and the consumption of seven food groups, including whole grains, fruits and vegetables, fish, nuts, high-fat dairy products, eggs, and red meat. Study period was of 13 years and within this time, 1,140 heart failure hospitalizations were identified. Heart failure risk was higher in the case of egg intake as compared to whole grain intake [74].

The relationship between egg consumption and mortality from coronary heart disease and stroke was investigated in a study including 14,943 participants (6,833 men and 8,113 women aged over 17 years). Findings revealed that higher egg intake was not linked to increased coronary heart disease mortality.

Additionally, among men, a significant inverse association was identified between egg consumption and stroke-related mortality [75].

The association between egg consumption and incidence of cardiovascular diseases was investigated in a cohort study of 14,185 university graduates. Subjects were divided into four groups based on egg consumption: no or less than 1 egg per week, 1 egg per week, 2-4 eggs per week and more than 4 eggs per week. Over a six-year study period, 91 cases of cardiovascular disease were identified. The findings indicated that egg consumption exceeding four eggs per week was not linked to an increased risk of cardiovascular disease compared with consuming none or less than one egg per week [76].

Egg consumption and the risk of type 2 diabetes in 20,703 men and 36,295 women were evaluated. Egg consumption and the risk of type 2 diabetes were evaluated in 20,703 men and 36,295 women. During the follow-up period, 1,921 men and 2,112 women developed type 2 diabetes. The study investigated whether habitual egg consumption was associated with the incidence of type 2 diabetes and reported an association between egg intake and diabetes risk, highlighting the need to consider overall dietary patterns and individual metabolic status when interpreting these findings [77].

In a cohort study including 3,898 participants aged above 65 years, researchers evaluated the relationship between egg consumption and the risk of developing type 2 diabetes. The results showed no association between egg intake and increased incidence of type 2 diabetes. Additionally, dietary cholesterol intake was not linked to significant differences in fasting glucose, insulin concentrations, or measures of insulin resistance [78].

5.3. Neurocognition

Diet plays a crucial role in brain function and has important implications for mental health and neurodegenerative diseases. Several studies have reported positive associations between dietary nutrient intake and cognitive performance, mental health

status, and the prevention of neurological disorders [34, 35, 37, 79]. Nutrition influences cognitive processes throughout the lifespan, as both brain structure and function are strongly dependent on adequate nutrient supply [80]. Cognition encompasses a range of mental processes involved in acquiring and processing knowledge, including learning, attention, memory, and intelligence [79].

Eggs provide a variety of essential nutrients such as high-quality proteins, essential fatty acids, B vitamins, vitamins A and D, and selenium that support cognitive health. In addition, specific compounds found in eggs, such as lutein and choline, have been associated with brain development and a reduced risk of cognitive decline [81]. Evidence from a randomized controlled trial conducted in Ecuador involving 163 children aged 6–9 months showed that the daily consumption of one egg for six months significantly improved growth in young children [82]. Similarly, data from the National Health and Nutrition Examination Survey indicated that infants aged 6–24 months who consumed eggs had higher intakes of several key nutrients, including protein, lutein, zeaxanthin, choline, vitamin B12, selenium, and phosphorus, while also consuming lower amounts of added and total sugars compared with non-consumers [83].

Additional evidence has been reported in older populations. A study involving 178 institutionalized adults aged over 65 years showed that individuals with higher egg consumption achieved better results in the Short Portable Mental Status Questionnaire, suggesting that egg intake may help maintain cognitive capacity [84]. Furthermore, research investigating the relationship between cholesterol and egg consumption and the risk of dementia and Alzheimer's disease in middle-aged and older men found no association between egg intake and an increased risk of these conditions. In contrast, individuals who

consumed eggs demonstrated better performance in neuropsychological assessments of executive function and frontal lobe activity, including the Trail Making Test and the Verbal Fluency Test [85].

An observational study involving 404 adults aged over 60 years, with or without mild cognitive impairment, also suggested that higher daily egg consumption may help reduce the risk of developing mild cognitive impairment [86]. Overall, these findings suggest that egg consumption may contribute to the maintenance of cognitive function and may be associated with a lower risk of cognitive decline.

5.4. Sports nutrition

Eggs are a nutritious food, particularly for athletes that may benefit from egg consumption and have a healthy diet that supports their nutrients demands. Sports performance and health are dependent on skeletal muscle [69]. A recent crossover study evaluated the effects of consuming whole eggs versus egg whites on whole-body and skeletal muscle protein metabolism. The results indicated that the plasma appearance rate of protein-derived leucine was faster after the ingestion of egg whites compared with whole eggs. However, despite providing the same protein content, the ingestion of whole eggs immediately after resistance exercise resulted in a greater stimulation of myofibrillar protein synthesis than egg whites alone [87].

In another study, the dose–response relationship between egg protein intake and muscle as well as albumin protein synthesis following resistance exercise was investigated in six healthy young men. Participants consumed five beverages containing different amounts of whole egg protein (0, 5, 10, 20, and 40 g). Measurements taken four hours after exercise showed that the ingestion of 20 g of egg protein produced the greatest stimulation of muscle and albumin protein

synthesis. Additionally, leucine oxidation increased significantly after the intake of 20 g and 40 g of egg protein [88].

Thirty-six (36) older adults (60–62 years) participated in a 12-week resistance training program while consuming diets with either low or high protein content, the high-protein diet include eggs. The results showed that moderate increases in protein intake and differences in dietary cholesterol did not significantly affect changes in body composition, skeletal muscle fiber size, or serum lipid and lipoprotein profiles following resistance training [89].

Plasma lipid and apolipoprotein profile changes were analyzed in 5 women and 7 men, healthy and unfit after a 6-week endurance exercise training program. For 8 weeks, subjects consumed an egg or no egg diet. Independent of the diet after training, a significant increase in high-density lipoprotein cholesterol, a decrease in apolipoprotein B levels and a reduction in plasma cholesterol ester transfer protein activity were observed [90].

In a human study (25 subjects, 18-35 years), the effect of an intake of 2 eggs per day compared to a bagel-based breakfast, combined with resistance training three times per week, prior to breakfast was assessed in order to identify the risk factors for chronic diseases. The 2-egg breakfast consumed for 12 weeks had no negative effect on lipids and promoted improvements in plasma triglycerides [91].

5.5. Eye health

Eggs contain lutein and zeaxanthin, two carotenoids that can improve visual acuity and may provide protection against some diseases of the macula [92] due to the fact that these carotenoids are absorbed into the human bloodstream more efficiently [40].

In a randomized crossover study involving 33 men and women, participants consumed one egg per day for five weeks. The results showed significant increases in serum lutein (26%) and zeaxanthin (38%), while no changes were observed in total cholesterol,

LDL cholesterol, HDL cholesterol, or triacylglycerol concentrations [93]. Similarly, another study reported that the daily consumption of three eggs/day for twelve weeks resulted in increases of 21% in lutein and 48% in zeaxanthin levels in 20 adult participants [35]. These findings suggest that egg yolk represents an important dietary source of lutein and zeaxanthin, which may contribute to the prevention of ocular conditions such as cataracts and age-related macular degeneration in adults.

Lutein and zeaxanthin concentrations in plasma after dietary supplementation with egg yolk were investigated in a study that involved 12 moderately hypercholesterolemic men and women. The subjects received two baseline diets containing beef tallow or corn oil. After diets supplementation with cooked chicken eggs, the group that received a beef tallow diet supplemented with eggs showed an increased plasma lutein by 28% and zeaxanthin by 142%. In the case of corn oil diet supplemented with eggs, individuals recorded a plasma lutein concentration increase by 50% and zeaxanthin by 114%. LDL-cholesterol levels increased by 8-11% after egg yolk was added to the two diets [94].

A crossover study conducted in 10 healthy men evaluated the bioavailability of lutein from four different dietary sources: a lutein supplement, a lutein ester supplement, spinach, and lutein-enriched eggs. Participants consumed each diet in random order, and the results indicated that lutein derived from eggs exhibited higher bioavailability compared with the other tested sources [95].

Another randomized crossover study investigated the effects of consuming one egg per day for five weeks on serum concentrations of lutein, zeaxanthin, lipids, and lipoprotein cholesterol in 33 adults aged over 60 years. The findings demonstrated that daily egg consumption significantly

increased serum lutein and zeaxanthin levels without affecting total serum lipids or lipoprotein cholesterol concentrations [93]. Similarly, a four-week intervention in 50 healthy young men and women showed that consuming a breakfast containing two eggs led to higher plasma carotenoid concentrations compared with an oatmeal-based breakfast [96].

The impact of egg intake on macular pigments was also examined in a 12-week study involving 24 women aged 24–59 years. Participants received either a lutein supplement or eggs (six eggs per week containing either 331 µg or 964 µg of lutein and zeaxanthin per yolk). Increased serum zeaxanthin concentrations were observed in both egg groups, although no significant changes were detected for lutein. In addition, macular pigment levels increased following the egg-based dietary interventions [97].

These findings are consistent with another study showing that the intake of four egg yolks per day for five weeks increased macular pigment levels by approximately 50%, while the consumption of two eggs per day resulted in a 31% increase among older adults with initially low macular pigment levels [98].

5.6. Bone health

Bones are composed primarily of a mineral component and an organic matrix, which together provide mechanical support, mobility, and flexibility to the human body. In addition to enabling movement, bones protect internal organs, store essential minerals, and function as a reservoir for calcium, thereby helping maintain calcium homeostasis [99]. During the aging process, increased bone resorption may occur, potentially leading to detrimental effects on skeletal integrity. Nutritional deficiencies, particularly in minerals, vitamins, and proteins, can contribute to the development of weak and poorly mineralized bones [34]. Consequently, adequate nutrition plays a critical role in maintaining bone health.

Eggs are recognized as a valuable dietary source of vitamins and other nutrients [15]. A single egg provides more than 10% of the recommended daily intake for several vitamins, including vitamin D, which is essential for bone metabolism and calcium absorption. Notably, vitamin C is the only major vitamin not present in eggs [34].

Although, eggs contain several nutrients potentially beneficial for bone health, evidence regarding the effects of habitual egg consumption on skeletal outcomes in older adults remains limited and somewhat inconsistent. Only a small number of studies have examined the relationship between egg intake and fracture risk [90-98], and their findings are not entirely consistent. Nevertheless, eggs contain various bioactive compounds - including ovotransferrin, carotenoids, and vitamin D - that may support bone formation, reduce bone resorption, and enhance calcium absorption [100].

The Skeletal and Cognitive Effects of Nutrition from Eggs study investigated whether increased intake of whole eggs (8–10 eggs per week) over a nine-month period could influence bone mineral content, bone mineral density, and tibial cortical bone characteristics in children entering early puberty. Although the study did not identify statistically significant differences, the bone mineral content-for-age Z-scores in the egg-consuming group showed a tendency toward improvement. Importantly, serum lipid concentrations remained unchanged, suggesting that increased egg intake was safe and might provide potential benefits for bone development. These findings highlight the complexity of nutritional interventions during early puberty and emphasized the need for longer and more rigorously controlled studies to better understand the role of eggs in skeletal development during childhood [101].

In older adults, whole egg consumption has been positively associated with higher whole-body bone mineral density and a

lower risk of fractures. These effects may be attributed to the combined action of several nutrients present in eggs, including proteins, carotenoids, choline, and polyunsaturated fatty acids, which can stimulate osteoblast activity, inhibit osteoclast-mediated bone resorption, and support bone remodeling processes [100]. Therefore, eggs may represent a nutrient-dense and accessible dietary component with potential benefits for skeletal health. However, further randomized controlled trials are required to confirm these associations and to support evidence-based recommendations regarding egg consumption for the prevention of osteoporosis in aging populations [102].

6. Conclusions

The present review underscores that hen eggs constitute a nutritionally dense and structurally complex food matrix, in which high-quality proteins, essential fatty acids, phospholipids, vitamins, minerals and carotenoids coexist with a wide array of bioactive properties. Major egg proteins, including ovalbumin, ovotransferrin, lysozyme, ovomucin and cystatin, exhibit antimicrobial, antioxidant, immunomodulatory, anti-hypertensive and antiresorptive activities, while yolk phospholipids and choline are critical for membrane integrity, lipoprotein metabolism and normal neurological function. In addition, lutein and zeaxanthin from egg yolk are highly bioavailable and contribute meaningfully to ocular protection and neurocognitive health.

Data from epidemiological studies and clinical trials indicate that, within an otherwise balanced diet, moderate egg consumption can contribute to appetite regulation and body weight management, primarily through the high satiating capacity of egg proteins and their effects on postprandial hormonal responses. In the context of sports nutrition, whole-egg ingestion appears to stimulate myofibrillar

protein synthesis to a greater extent than iso-nitrogenous egg white alone, suggesting that yolk-derived nutrients exert synergistic effects that potentiate the anabolic response to resistance exercise. Furthermore, in healthy and overweight individuals, egg intake generally does not adversely affect plasma lipid profiles, and most studies do not support an increased cardiovascular risk associated with moderate consumption in the general population.

Findings related to cardiometabolic health, type 2 diabetes and skeletal outcomes are more heterogeneous and seem to depend on baseline risk, overall dietary pattern and coexisting metabolic disturbances. While infrequent to moderate egg intake is not consistently associated with higher incidence of cardiovascular disease or type 2 diabetes, some data suggested that individuals with established diabetes or marked cardiometabolic risk may require a more cautious, individualized dietary approach. Preliminary evidence also points to potential benefits of eggs for bone health in both growing children and older adults; however, current results remain limited and inconclusive, warranting further investigation.

Overall, the evidence supports the classification of eggs as functional foods whose nutritional and bioactive components act in a complementary and synergistic manner to promote health and contribute to the prevention or attenuation of nutrition-related disorders across the lifespan. Nonetheless, important gaps remain regarding optimal intake levels, population-specific recommendations and long-term safety in high-risk groups. Future research should prioritize well-designed randomized controlled trials and prospective cohorts to clarify dose-response relationships, explore interactions with dietary patterns and lifestyle factors, and elucidate mechanistic pathways linking egg-derived bioactive compounds to

cardiometabolic, neurocognitive, skeletal and ocular outcomes.

7. References

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