Title

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Journal
Nutrition reviews, 72(6)

ISSN
0029-6643

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Publication Date
2014-06-01

DOI
10.1111/nure.12107

Peer reviewed

Special Article

NUTRITION REVIEWS

Eggs: the uncracked potential for improving maternal and young child nutrition among the world's poor

Lora L Iannotti, Chessa K Lutter, David A Bunn, and Christine P Stewart

Eggs have been consumed throughout human history, though the full potential of this nutritionally complete food has yet to be realized in many resource-poor settings around the world. Eggs provide essential fatty acids, proteins, choline, vitamins A and B_{12}, selenium, and other critical nutrients at levels above or comparable to those found in other animal-source foods, but they are relatively more affordable. Cultural beliefs about the digestibility and cleanliness of eggs, as well as environmental concerns arising from hygiene practices and toxin exposures, remain as barriers to widespread egg consumption. There is also regional variability in egg intake levels. In Latin American countries, on average, greater proportions of young children consume eggs than in Asian or African countries. In China and Indonesia, nutrition education and social marketing have been associated with greater amounts of eggs in the diets of young children, though generally, evidence from interventions is minimal. Homestead chicken-and-egg production with appropriate vaccination, extension service, and other supports can simultaneously address poverty and nutrition in very poor rural households. With undernutrition remaining a significant problem in many parts of the world, eggs may be an uncracked part of the solution.

INTRODUCTION

Eggs are uniquely supportive of early growth and developmental processes. The egg, as a specialized reproductive cell, must sustain life for the gestational period by providing complete nutrition and immune defenses. In addition, it may offer particular advantages for maternal and young child nutrition, especially in vulnerable populations living in resource-poor environments. As a relatively more affordable animal-source food, eggs can contribute to household food security through homestead chicken-and-egg production systems and market access.

Evidence is limited in support of egg-related interventions for nutrition outcomes in developing countries. Presented here is a review of the existing literature and the rationale for investing further in the science, programming, and policy aspects of eggs for use in maternal and child nutrition in developing countries. The focus of this review is on the more ubiquitous chicken egg, though in many parts of the world, eggs from other fowl, such as duck or guinea fowl, are also consumed.

The review is organized into five sections. First, egg nutrient composition is described, with a focus on the macro- and micronutrients known to be lacking in the diets of children from resource-poor contexts. Next, the direct role eggs may play in maternal and child nutrition and in relation to existing guidelines is explored, with recent findings on allergies included. Sections on cultural factors and environmental issues associated with egg production, handling, and consumption follow. The last section provides evidence demonstrating

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Key words: choline, eggs, homestead chicken and egg production, maternal nutrition, pediatric nutrition, undernutrition, vitamin B_{12}

doi:10.1111/nure.12107

how the homestead chicken-and-egg production model has been used to increase egg availability and access to eggs in vulnerable populations. In the conclusion, recommendations are offered for future research, programming, and policies to more fully tap the potential of eggs in under-resourced settings.

Brief history of eggs in the human diet

Consumption of the eggs of wild fowl, such as pigeon, peafowl, ostrich, quail, ducks, and pelicans, among others, is thought to date to ancient times, while the consumption of chicken eggs has a relatively short history.[1] The *Gallus gallus*, or domesticated chicken, was believed to be a descendent of birds from the jungles of Southeast Asia, domesticated before 7,500 BCE.[2,3] China has a long and consistent history of dietary intake of eggs. Recipes from the Greeks and Romans suggest the use of eggs for baking, in custards, in omelets, and prepared hard-boiled.[4] During the Middle Ages in Europe, eggs were considered meat by the Catholic Church, and thus their consumption was restricted during Lent and other holy seasons. The Easter custom of decorating eggs after dipping them in fat or wax arose from the need to preserve eggs for later consumption.[4]

The opening of trade channels between China and England in the early 19th century led to rapid changes in chicken breeding and expanded efforts to increase the production and quality of poultry. By the 20th century, however, poultry sheds were replaced with farms, ranches, and, eventually, industrialized operations of mass production. In the United States, improved production efficiencies and technological advances such as refrigeration served to increase egg production and quality, but at the expense of breed diversity and, sometimes, hygiene.[3] In certain populations through history, the consumption of eggs has been discouraged for economic and social reasons. As an example, Toussaint-Samat describes the Mossi ethnic group in Burkina Faso, who have traditionally considered eggs to be community property, the consumption of which deprives the community of future broods and disturbs the natural order of the life cycle.[4]

EGG NUTRIENT COMPOSITION

Eggs are specialized cells designed in nature for reproduction and nutritive support from conception onward. Similar to seeds or even milk, eggs serve as the sole stock of nutrients until the organism can survive more independently in the environment. The comprehensive egg package, while designed for the chicken offspring, likely has health advantages for young children as well. Eggs comprise two distinct parts, the yolk and white, which differ in biological function and composition (Figure 1).[5] The yolk's purpose is primarily nutritive, while the white

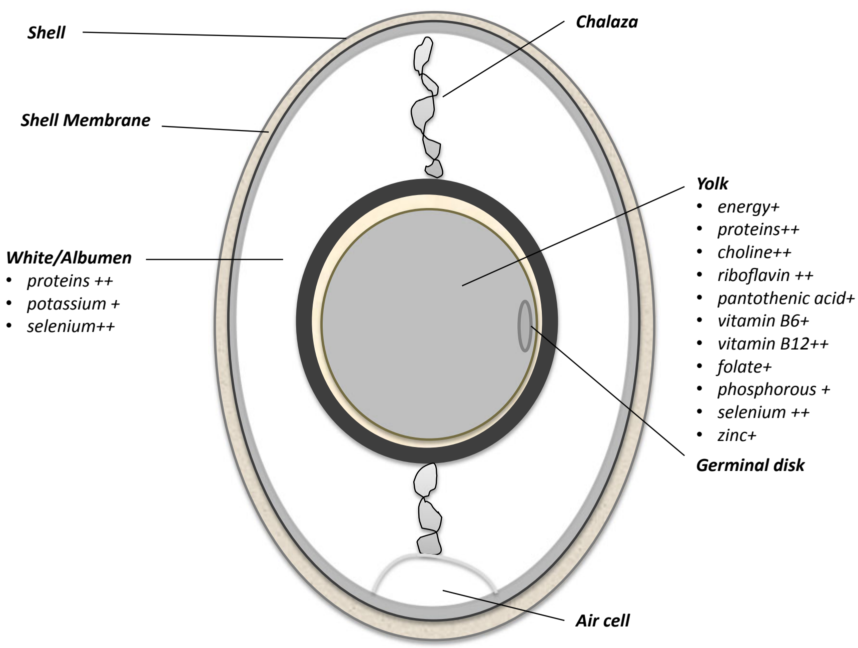

Figure 1 **Illustration of the components of a chicken egg.** The nutrient contents of a whole large egg (60 g) are shown and are indicated by ++ if present at 50% or higher of the adequate intake (AI) or recommended dietary allowance (RDA) level for healthy, breastfed children 7–12 months of age and by + if present at 20–50% of the AI/RDA for healthy, breastfed children 7–12 months of age.[5]

Table 1 **Nutrient content of eggs and human milk, along with recommended levels of dietary intakes of eggs for infants aged 7–12 months.**

Nutrient	Unit of measure	AI[a]	Egg (whole, 60 g)	Egg (yolk, 17 g)	Egg (white, 33 g)	Whole egg per 100 g	Human milk per 100 g
Energy	kcal	769–858[b]	72	55	17	143	70
Protein	g	11	6.28	2.7	3.6	12.56	1.03
Lipids (total)	g	30	4.76	4.51	0.06	9.51	4.38
Linoleic acid (18:2 n-6)	g	4.6	0.77	0.6	0	1.53	0.37
α-Linolenic acid (18:3 n-3)	g	0.5	0.02	0.02	0	0.04	0.05
DHA (22:6 n-3)	g	–	0.03	0.02	0	0.06	0
Carbohydrates	g	–	0.36	0.61	0.24	0.72	2.12
Vitamins							
Vitamin A, RAE	μg	500	80	65	0	160	61
Thiamin (B_1)	mg	0.3	0.02	0.03	0.001	0.04	0.01
Riboflavin (B_2)	mg	0.4	0.23	0.09	0.15	0.46	0.04
Niacin (B_3)	mg	4	0.04	0.01	0.04	0.08	0.18
Pantothenic acid (B_5)	mg	1.8	0.77	0.51	0.06	1.53	0.22
Vitamin B_6	mg	0.3	0.09	0.06	0.002	0.17	0.01
Vitamin B_{12}	μg	0.5	0.44	0.33	0.03	0.89	0.05
Folate, DFE	μg	80	24	25	1	47	5
Choline	mg	150	146.9	139.4	0.4	293.8	16
Vitamin C (ascorbic acid)	mg	50	0	0	0	0	5
Vitamin D (D_2+D_3)	μg	10	1	0.9	0	2	0.1
Vitamin E (α-tocopherol)	mg	5	0.52	0.44	0	1.05	0.08
Vitamin K	μg	2.5	0.2	0.1	0	0.3	0.3
Minerals							
Calcium	mg	260	28	22	2	56	32
Copper	mg	0.22	0.04	0.01	0.01	0.07	0.05
Iodine	μg	130	–	–	–	–	–
Iron	mg	11	0.88	0.46	0.03	1.75	0.03
Magnesium	mg	75	6	1	4	12	3
Manganese	mg	0.6	0.01	0.01	0.004	0.03	0.03
Phosphorus	mg	275	99	66	5	198	14
Potassium	mg	700	69	19	54	138	51
Selenium	μg	20	15.4	9.5	6.6	30.7	1.8
Sodium	mg		71	8	55	142	17
Zinc	mg		0.64	0.39	0.01	1.29	0.17

Abbreviations: AI, adequate intake; DFE, dietary folate equivalents; DHA, docosahexaenoic acid; RAE, retinol activity equivalents.
[a] IOM (2013).[5]
[b] Total energy required, including an assumed average breast milk intake of 379–413 kcal.[6]

serves as a defense system against pathogenic invaders and as physical support. Egg generation begins inside the hen ovary, where concentric layers of fats and proteins are first added to the germ cell to form the yolk.[3] After release from the ovary, the white is gradually added over several hours as it passes through the oviduct. The protein albumen secreted from cells lining the oviduct first form the chalazae, which are elastic twisted proteins that suspend and protect the yolk. Next, alternating thin and thick layers of albumen are added, as well as two antimicrobial membranes. Once in the hen uterus, water and salts are pumped into the white, and finally, the shell is formed with calcium carbonate and other proteins.[3]

With some exceptions, the egg yolk provides the greater proportion of nutrients than the white (Table 1).[5,6] Egg white contains mostly water and protective proteins that sequester nutrients like iron and block enzymatic activity. Magnesium, potassium, and sodium are also provided at higher levels in the white than in the yolk.

Macronutrients: essential fatty acids and protein profile of eggs

Eggs are an important source of essential fatty acids (EFAs) that may be further enriched and are also a nearly complete protein. In recent years, there has been renewed focus on the importance of EFAs, particularly docosahexaenoic acid (DHA), during pregnancy and early childhood. Omega-3 (n-3) and omega-6 (n-6) fatty acids are critical for early brain development and visual acuity.[7,8] Empirical evidence of the effects of EFAs in populations of developing countries, while limited, suggests there may be benefits for birthweight and birth length, gestational age, and growth and development of young children aged 6–24 months.[9] Some studies have demonstrated the important contribution of eggs to EFA intake, specifically DHA.[10,11]

Egg yolks contain a higher ratio (30:1) of linoleic acid (18:2 n-6) to α-linolenic acid (18:3 n-3) than is desired for efficient conversion of α-linolenic acid to DHA, with some variability across eggs from different avian species.[12,13] Several studies in which eggs were "field" fortified through the use of n-3 supplements in hen feed and other technologies showed increased DHA content, which was associated with positive health and nutrition outcomes.[14,15] One randomized controlled trial compared nutrition outcomes in breastfed and nonbreastfed infants who consumed n-3 fatty-acid-enriched eggs or regular eggs 4 times per week from 6 to 12 months of age. There was also a control group of children who received no intervention. The n-3 and regular eggs were purchased from the same company and were similar in size, appearance, taste, and smell. Erythrocyte DHA concentrations were significantly higher in the n-3 egg group than in the regular egg group, but there was also a trend toward higher DHA levels in the regular egg group than in the control group.[15] Range-fed chickens have been shown to produce eggs with higher levels of n-3 fatty acids than caged birds.[16]

For several decades, the high cholesterol content in egg yolk was a concern in public health because of links to increased risk of coronary heart disease and stroke. However, recent reviews of the evidence and newer studies have sufficiently refuted this belief.[17–19] During early pregnancy, maternal cholesterol is important in placental hormone biosynthesis, implantation, and vascularization processes. Some evidence shows that low cholesterol early in pregnancy may lead to poor birth outcomes, particularly preterm birth.[20] The United States is one of the few remaining countries to maintain dietary guidelines for reducing cholesterol intake.[21,22]

Eggs are considered a perfect protein source, with an amino acid profile against which other proteins are compared.[23] The protein-digestibility-corrected amino acid score (PDCAAS) evaluates foods using reference patterns of essential or indispensable amino acids to achieve nitrogen balance across different age groups.[24] A PDCAAS of less than 1 (or 100% when converted to percentile) indicates at least one amino acid is limiting, while a score that exceeds 1 meets the requirements for all 9 essential amino acids. For children ages 6 months to 5 years, the PDCAAS for eggs is 118%, compared with 92–94% for meat and fish, 90–93% for soya, and 35–57% for rice, wheat, and maize.[24] Eggs are also an affordable protein source. According to the Nutrient Rich Foods Index, a nutrient profile model, eggs are the lowest-cost source of protein in the United States, among a comprehensive list of foods.[25]

Protein function differs somewhat in the egg white and yolk constituents. After water, proteins such as ovalbumin, ovotransferrin, ovomucin, and lysozyme are the major components of albumen, or the egg white.[26] Ovalbumin is thought to inhibit protein-digesting enzymes, while ovomucin structurally supports the yolk and impedes pathogen invasion.[3] Ovotransferrin sequesters iron away from bacteria for the developing chick. Proteins in egg yolk likely play a nutritive role primarily, though they also play critical emulsifying, antimicrobial, and antioxidant roles. Low-density lipoproteins comprise two-thirds of the yolk solids, while high-density lipoproteins, which have critical antioxidant functions and antimicrobial activity against *Salmonella enteritidis*, *Salmonella typhimurium*, and *Escherichia coli*, are also present.[26] The characteristic sulfur smell of cooked eggs may arise from the sulfur content of the shell membrane, though eggs are a good source of proteins rich in sulfur amino acids, methionine, and cysteine.

Micronutrients: choline, vitamins A and B_{12}, and minerals

Eggs contain high concentrations of choline, only recently recognized as an essential nutrient.[27] Choline is an important precursor of phospholipids (phosphatidylcholine and sphingomyelin), needed for cell division, growth, and membrane signaling; acetylcholine, which influences neurotransmission, neurogenesis, myelination, and synapse formation; and betaine, which donates a methyl group in the homocysteine production pathway.[28,29] While choline can be produced endogeneously, dietary intakes are still necessary, with evidence showing high requirements in the postnatal period.[27,28] Intake inadequacies during pregnancy, lactation, and infancy may result in neural tube defects,[30] changes in brain structure and function in offspring,[31] adverse pregnancy outcomes,[32] and impaired language development during early childhood.[33] Choline, through its role as a methyl donor, also may have epigenetic effects during pregnancy[34] and influence phosphatidylcholine enrichment of DHA in nonpregnant women.[35] A wide variety of foods, ranging from plant-based sources (soy, wheat germ, quinoa, almonds, peas, cauliflower, and broccoli) to animal sources (eggs, milk, and meat, especially liver and fish), provide choline in free or esterified forms, but eggs provide more choline per kilocalorie than other foods. The yolk from one large egg provides 146.9 mg of choline, or 98% of the Institute of Medicine's Adequate Intake for children aged 7–12 months and 73% for children 4–8 years.

Eggs yolks were integral to vitamin A discoveries over the last century. In 1891, scientists published findings describing a fat-soluble substance in egg yolk that contributed to growth but was not present in other fats such as lard and olive oil.[36] The substance would eventually be labeled vitamin A. Thus far, no randomized controlled trials have examined the intake of eggs on vitamin A status, but some observational studies have found eggs in the diet to be protective against night blindness[37,38] and xerophthalmia.[39,40] While there is minimal evidence in nutritionally vulnerable populations, egg intake has been shown to improve plasma carotenoid status in adults with metabolic syndrome[41] and in vegetarians.[42] Eggs are a good source of lutein and zeaxanthin, carotenoids that protect against lipoprotein oxidation.[21] Other vitamins critical to the health of vulnerable populations, such as E, D, B_{12}, and folate, are also found in eggs.[12,13] One study examining the adequacy of micronutrient intakes in rural Bangladesh found eggs contributed 40.8% of vitamin B_{12} intake among young children and 29.4% among women.[43]

Eggs may also contribute to mineral intake. Both the yolk and the white contain high levels of selenium and together can make an important contribution toward meeting requirements in children.[44] This trace mineral is important for immune function and for its antioxidant and epigenetic effects.[45] Eggs have been shown to make an important contribution to iodine status among children of preschool age[46] and school age.[47] Egg yolk in the diets of both breastfed and nonbreastfed children increased plasma iron and transferrin saturation in a trial examining the effects of n-3-enriched eggs, though other markers of iron status, such as ferritin and hemoglobin concentration, were not affected.[14] One study in Cameroon showed that adding boiled egg yolks to complementary foods (solid foods or nutritive liquids given to infants and young children to complement breastfeeding after 6 months of age) increased energy and nutrient densities in the traditional maize porridge in vitro, while adding lemon juice further increased zinc, iron, and calcium availability.[48] In the Philippines, egg yolk added to maize- and rice-based complementary foods increased iron and zinc content while reducing phytate and penta-inositol phosphate concentrations and improving phytate/zinc and phytate/iron molar ratios.[49] Egg yolk added to the complementary foods reduced both ratios to levels below established thresholds for increased zinc and iron absorption. Only chicken liver performed better than egg yolk for improving zinc and iron bioavailability in the complementary foods. The study also evaluated small soft-boned fish and mung bean grits when comparing mineral-related outcomes. To conclude, eggs provide several critical micro- and macronutrients, often in highly bioavailable forms, that can enhance plant-based diets for children living in developing countries.

EGGS FOR MATERNAL AND YOUNG CHILD NUTRITION

Eggs contribute to dietary diversity. They are one of three groups of animal-source foods, together with flesh foods and dairy products, included in the seven food groups used by the World Health Organization to assess minimum dietary diversity in infants and young children.[50] Therefore, eggs contribute separately to the calculation of this indicator, which specifies that a threshold of four of the seven food groups be consumed. Relative to their potential to improve child nutrition, eggs are underused in the diets of young children.[51] Despite this, nutritionists and pediatricians in many countries continue to oppose the early introduction of eggs because of concerns about allergies, suggesting that the curricula in nutrition and medical schools are not abreast of the most recent scientific evidence, reviewed below in the subsection titled "Egg allergies."

The MEASURE Demographic and Health Surveys,[52] the largest source of nationally representative data on child nutrition in developing countries, ask specifically about egg consumption in the previous 24 hours. Although publications resulting from these surveys group eggs with meat, poultry, fish, and eggs in summary tables, the prevalence of egg intake among children may be calculated from the raw data. The results from 32 countries (19 in Africa, 6 in Asia, and 7 in Latin America and the Caribbean) for children less than 24 months of age show that eggs are consumed most frequently by children in Latin America, followed by those in Asia and then Africa (Table 2).

In Latin America and the Caribbean, egg consumption increases with child age. By year 2, in many countries, approximately one-half of the children are consuming eggs. The situation in Africa is remarkably different, with extremely low consumption in almost all age groups in the countries surveyed, with a few exceptions such as Ghana and Swaziland; however, even in these countries, less than one-third of the children aged 12–23.9 months consume eggs. In 10 African countries, egg consumption was less than 10% among all children, and most of these countries showed very little variation with age. In Asia, egg consumption was between that of Africa and Latin America and the Caribbean. India, where the population is primarily vegetarian, was a notable outlier, with very low prevalences of egg consumption across all age groups compared with other countries in the region. Among the two countries with data from sequential surveys, Zimbabwe showed a 55% increase between 2005–2006 and 2010–2011 (from 8.8% to 13.7%), whereas Uganda showed a 40% decrease (from 9.3% to 5.6%). Egg consumption is similarly low in some wealthier countries; for example, the median usual intake of eggs in the United States is 0.2/day

Table 2 **Prevalence (%) of egg consumption in the previous 24 hours, based on nationally representative surveys conducted 2004–2011.**[a]

Country and year	Child age			
Africa	6–8.9 mo	9–11.9 mo	12–23.9 mo	Total, 6–23.9 mo
Burkina Faso, 2010	1.8	5	5.7	4.9
Burundi, 2010	1.5	4.5	4.5	4
Ethiopia, 2011	7.6	9	8.4	8.3
Ghana, 2008	11.5	20.9	28.8	24.3
Lesotho, 2009	4.1	2.3	4.9	4.3
Liberia, 2007	8.8	16.4	17.4	15.5
Madagascar, 2009–09	1.8	3.9	5.7	4.6
Malawi, 2010	5.4	12.4	12.9	11.4
Mozambique, 2011	10.7	13.8	21.1	18
Namibia, 2006–07	11.7	26.2	20.7	19.9
Nigeria, 2008	12	19.1	19.8	18.1
Rwanda, 2010	3.3	8.4	3.9	4.5
Senegal, 2010–11	4.7	6.4	10.8	9
Sierra Leone, 2008	7.6	7.7	10	9.1
Swaziland, 2006–07	15	22.4	29.8	25.5
Tanzania, 2010	6.8	6.8	8.8	8.1
Uganda, 2006	4.8	4.9	5.9	5.6
Zambia, 2007	12.7	19.8	18	17.4
Zimbabwe, 2010–11	6	12.6	16.7	13.7
Regional average	7.25	11.71	13.36	11.91
Asia				
Bangladesh, 2011	12.6	22.4	29.5	25.2
Cambodia, 2005	12.8	16.8	20.6	18.6
India, 2007	1	3	7.2	5.3
Nepal, 2006	11.7	26.2	20.7	19.9
Philippines, 2008	22.4	37.7	40.1	36.6
Timor-Leste, 2009	19.7	30	34.2	30.8
Regional average	15.84	27.83	32.93	28.90
Latin America & the Caribbean				
Bolivia, 2008	20.7	34.4	43.1	38.0
Colombia, 2010	18.5	34.8	53.9	44.1
Dominican Republic, 2007	22.3	36.6	44.2	38.8
Guyana, 2009	29.6	34.7	35.2	33.9
Haiti, 2005–06	6.4	9.3	8.3	8.2
Honduras, 2005–06	37	55.3	64.3	57.5
Peru, 2004–06	25.4	38.1	43.7	39.6
Regional average	22.84	34.74	41.81	37.16

[a] Data from ICF International, The DHS Program, Demographic and Health Surveys.[52]

among children aged 1–3 years and 0.2–0.3/day among women aged 19–50 years.[53]

Among small-scale studies of low-income populations in Asia, Africa, and Latin America, the prevalence of egg consumption by infants and young children is, with few exceptions, less than 16%.[54] Among infants 6–8 months of age, less than 6% consumed eggs in the previous day in Ghana, Madagascar, Malawi, and Bangladesh, and only 14% in the Philippines did so. In Peru, consumption was twice as high in a food-secure setting (24%) as in a poorer setting (11%). Only in Honduras was intake relatively high, at 42%. In these populations, consumption did not increase much with age. One study in Indonesia applied linear programming to develop complementary feeding recommendations based on locally available foods that have the potential to meet nutrient requirements for children aged 9–11 months.[55] Eggs were among the best local food sources to improve diet quality in this population of infants. Eggs are important to the maternal diet, not only because of their nutritional benefits to women but also because maternal dietary patterns are well documented to influence children's diets.[56–58] Unfortunately, few data are available to document maternal intake of eggs in developing countries.

In one of the few studies that examined egg consumption among mother and child dyads, data on food group intake, including eggs as a food group, were collected in Bangladesh, Vietnam, and Ethiopia.[56] Egg consumption in the previous 24 hours among young children was highest in Viet Nam and lowest in Ethiopia. In all countries, consumption increased between the ages of 6–8 months and 12–24 months. However, even in Viet Nam, the highest-consuming country, only about one-third of children aged 12–24 months consumed eggs. In Ethiopia, the lowest-consuming country, only 11.3% of children aged 12–24 months consumed eggs. Although eggs were consumed by only about 30% of children aged 6–24 months and 43% of mothers, they were one of the food groups, along with starchy staples, for which there was greater similarity of intake among mothers and children compared with other food groups. Therefore, promoting egg intake among pregnant women may also increase egg consumption among their children, once born.

Egg interventions: research and programming to improve infant and young child nutrition through eggs

Few studies have attempted to determine how egg consumption patterns can be changed through interventions. One study in rural Sichuan, China, evaluated a nutrition education intervention over a 1-year period.[59] This cluster-design study included two comparison groups (education and control) in separate, noncontiguous townships with approximately 12 villages each. Nutrition educators visited households once a month for a year to monitor growth and promote positive infant and young child nutrition. One message specific to improving the quality of complementary foods encouraged caregivers to give hard-boiled egg yolk, first mixed with breast milk, and later with rice porridge, to infants daily after the age of 4 months.

At the conclusion of the study, a higher percentage of mothers in the education group reported that egg yolk should be the first food for infants, and both food frequency questionnaires and 24-hour recalls confirmed higher consumption levels in the education group than in the control group. Among infants 4–6 months of age, 37% in the intervention group versus 16% in the control group received eggs the day of the interview ($P < 0.01$); among infants 7–9 months of age, 66% in the intervention group versus 41% in the control group received eggs ($P < 0.01$). Only among infants 10–12 months of age was there no difference: 67% versus 62% for the intervention and control groups, respectively. The reasons mothers gave for not giving eggs included "baby didn't like it" and "baby too small and can't digest it." As shown in many studies of infant and young child feeding, there was a gap between knowledge and behaviors. Although 65% of mothers in the intervention group and 21% in the control group reported that the first food fed should be egg yolk, only 37% in the intervention group and 16% in the control group actually gave egg yolk to their 4- to 6-month-old infants. Children in the intervention group showed improved growth at 12 months and reduced anemia prevalence compared with those in the control group.

The homestead food production (HFP) model described below has been applied to improve infant and young child nutrition directly, especially when behavior change communication strategies are integrated with livestock development.[60] An evaluation of the impact pathways in Cambodia showed that the HFP program was associated with increased animal ownership, increased income earned from HFP, and increased consumption of eggs and other micronutrient-rich foods by children less than 5 years of age.[61] However, there were no growth or health impacts demonstrated, and problems with the evaluation design limited inferences for HFP causality. Micronutrient intakes were shown to improve in conjunction with small-scale poultry production programming in Egypt, though improvement was not directly linked to eggs.[62] An older study in Bangladesh investigated the impact of a Participatory Livestock Development Project (PLDP) and small-scale poultry enterprise and found increases in poultry stock and egg production – but not egg consumption – among PLDP households.[63] Rather, results suggested the income earned from poultry production was used to purchase other foods, such as small fish. In Indonesia, a large-scale social marketing campaign promoting dark-green leafy vegetables and eggs was found to be successful in increasing egg consumption, with related increases noted in vitamin A intakes and serum retinol levels.[64]

The evidence shows that eggs are greatly underutilized in the diets of young children, particularly in many African countries but also in Latin America and the Caribbean. At the same time, some evidence shows that egg consumption among young children can be improved through counseling. Egg consumption among mothers is strongly related to that among their children, illustrating that encouraging mothers to consume eggs is likely to result in increased consumption, as well as nutrition, among their children. In view of the common practice of mixing eggs with other foods in a family pot, thereby diluting nutrient concentrations, there may also be a need to encourage mothers and children to consume one or more whole eggs per day.

Egg allergies

Evidence regarding food allergies in developing countries is limited, though egg allergies have been identified in parts of Asia, sub-Saharan Africa, and South America.[65] In some populations, egg allergies are the most common immunoglobulin E (IgE)-mediated food allergy in infants and young children. Since the 1990s, guidelines on infant and young child nutrition have recommended the delayed introduction of allergenic foods, including eggs, in order to allow for immune system maturation. A review of the literature from 1980 to 2006 showed that early exposure increased sensitivity and that chicken albumen (α-livetin) has been associated with IgE sensitivity.[66] More recent findings, however, reveal that earlier introduction of allergenic foods into the infant diet may in fact reduce the likelihood of sensitization.[67] In 2008, the American Academy of Pediatrics revised the 2000 recommendations, no longer advocating the delayed introduction of eggs, among other foods, until the age of 2 years, indicating there was little to support the previous guidelines.

Studies examining egg allergies specifically have come from industrialized countries but do reveal advantages to early introduction in terms of reduced sensitivity. One study in Australia demonstrated an increased odds of allergic reaction when parents reported introducing eggs later, at 10–12 months (adjusted odds ratio [AOR] 1.6; 95%CI 1.0–2.6) or after 12 months (AOR 3.4; 95%CI 1.8–6.5), compared with 4–6 months.[68] This study also showed reduced allergic reactions if egg was introduced as cooked (boiled, scrambled, fried, or poached) rather than baked (in cakes, biscuits, or similar products). Heat processing of eggs or cooking at high temperatures has previously been demonstrated to reduce sensitivity.[69] Another prospective analysis of data from a Finnish cohort of children with human leukocyte antigen (HLA)-conferred susceptibility to type 1 diabetes also showed increased risk of food-allergic sensitization with delayed introduction of eggs after 10.5 months of age in different adjusted logistic regression models.[70] Similarly, food sensitization was increased with delayed introduction of solid foods in a cohort of German infants.[71]

CULTURAL ISSUES AND EGGS

Recognizing the nutritional value of eggs, their ease of preparation, and their relative ease of consumption by young children, many educational programs to encourage change in infant and young child feeding behaviors have recommended eggs as a high-quality complementary food.[72] Despite such campaigns, cultural beliefs about the acceptability of eggs for pregnant women or young children, as well as intrahousehold food allocation practices and related economic factors, may serve as barriers to actual consumption.

Within some cultures, taboos exist around the feeding of eggs to young children.[73] In Nepal, cultural and religious beliefs about whether foods are "hot," "cold," or "pollution" or have "strengthening" or "weakening" properties can play strong roles in food choices during certain stages of the life cycle, such as pregnancy and early childhood, or during recovery from illness.[38] Within the Baitadi, Brahmin, and Chhetri castes, poultry are not reared because they are believed to be unclean.[74] Among some religions, vegetarianism is held as an ideal, with the consumption of meat, eggs, and seafood strictly prohibited. Among pregnant women in Nepal, "religious reasons" have been reported as the most frequently cited reason for not consuming eggs.[75] Mothers from multiple castes reported that they thought meat and eggs should be avoided in children under the age of 1 year because they are "difficult to digest."[74] On the other hand, eggs are considered "hot" and strength giving, particularly good to eat during times of illness.[76]

This belief about the digestibility of eggs and other animal-source foods has been reported in other countries as well, notably Ethiopia[77,78] and Vietnam.[79] Yet, in many contexts, eggs are also thought to have health-promoting potential. In Ethiopia, some mothers reported that eggs are good for children's health and should be fed to allow children to "grow physically and mentally strong."[77,78] In Zimbabwe, Niger, Haiti, Peru, and Mali, eggs are thought to be good for children[73,80–82] because they are rich in vitamins, they increase weight, and they make children feel good[80] or are thought to provide strength and energy and to help children grow well.[81,82]

Perception of cost constraints may limit the consumption of eggs by young children. Because eggs are relatively higher in cost than staple foods like rice, maize, and other grains, they are often reserved for special occasions or provided to adult male household members.[76,83] If purchased, eggs may not be fed directly to the child but instead may be mixed into a family pot and consumed by all household members, limiting the amount that a young child may actually consume.[84] While some programs might consider subsidizing the cost of eggs for young children, this may be insufficient to overcome perceived economic barriers. As an example, caregivers in Ghana have reported a fear of establishing taste preferences among their young children for foods that could not be obtained over the long term.[84] Indeed, early exposures to foods and flavors help to establish food acceptance and flavor preferences in later childhood.[85] On the other hand, programs that promote sustainable access to poultry and eggs may have greater success in introducing eggs into the diets of young children. In Ethiopia, mothers reported their willingness to feed eggs to their children if the costs were affordable and, in fact, within households that owned chickens, eggs were more frequently fed to young children.[77]

EGGS AND THE ENVIRONMENT

The ecology of egg production and consumption may affect public health. Environmental conditions within and around the home may lead to infection through the fecal-oral or other routes of zoonotic transmission. Adherence to proper hygiene practices, such as keeping young children away from chicken feces, can mitigate these effects. Exposure to toxins, such as aflatoxin, during poultry and egg production can similarly harm human health. On the other hand, smallholder egg production has repeatedly been shown to have minimal impact on the environment compared with other livestock activities.

Exposures to pathogens and toxins from eggs and poultry

In many rural environments, chickens are reared in close proximity to the home environment, often roosting within the home. Diarrheal disease is a leading cause of child morbidity and mortality worldwide, particularly among children living in poor environments with poor water quality and sanitation infrastructure. Transmission from poultry of pathogens such as nontyphoidal *Salmonella enterica* or *Campylobacter jejuni* can occur through consumption of raw or undercooked poultry meat or eggs or through fecal-oral routes.[86,87]

In rural environments where poultry fecal contamination around the home compound is pervasive, the risk of infant and young child exposure is high. The burden of diarrheal disease attributable to *Salmonella* infection is relatively low among children in much of Africa and Asia, though infection with *C. jejuni* is significantly associated with moderate-to-severe diarrhea in children in Asia.[88] There is limited information about the relative burden of these infections in Latin America. Although *Cryptosporidium* and *E. coli* are pathogens shared by humans and poultry, host species specificity or habitat adaptations limit the virulence or zoonotic transmission potential from poultry to humans.[89–91] Some strains of extraintestinal pathogenic *E. coli*, which cause colibacillosis in poultry and are similar to strains causing urinary tract infections or neonatal meningitis in humans, may represent an exception.[92] Zoonotic transmission of highly pathogenic avian influenza is also a risk of close contact with poultry, though infection in humans is extremely rare.[93] Transmission occurs through direct contact with infected birds, contact with fecal material or oral or nasal discharges, or consumption of undercooked meat. Proper cooking and household hygiene and sanitation practices can limit much of the potential for pathogen transmission.

Storage time and temperature are important determinants of egg quality and antimicrobial activity.[94] Egg storage guidance differs by context; in the village chicken program described in the "Homestead Chicken-and-Egg Production" section below, it is recommended that eggs be stored for no more than 5–7 days in a cool, shady place, but only 1–2 days in warmer temperatures (>20°C).[95] The recommended shelf life of eggs in the United States is 30 days with refrigeration,[96] while European legislation states that eggs should be stored at room temperature to avoid bacterial growth from condensation on eggs removed from cold storage.[97] Guidelines consistently recommend that the exterior of raw eggs not be washed to protect the integrity of the shell and cuticle coating. Historically, some cultures have applied a fat or oil coating on eggs to preserve them over longer periods, a practice now supported by empirical evidence.[98] Finally, evidence of the advantages of hard boiling eggs is limited but suggests this lengthens storage time by amounts that vary according to temperature and shell-coating methods.[99]

Ingestion of aflatoxin B1 (AFB1), a toxic metabolite of the fungi *Aspergillus flavus* and *Aspergillus parasiticus*, can lead to impaired immune status, stunting, hepatic disease, and liver cancer. Observational and experimental trials have shown that aflatoxin feed contamination may transfer to both poultry meat and eggs. Studies carried out in Cameroon showed detection of AFB1 in egg samples[100] and a higher concentration of aflatoxin in peanut meal than in maize feeds consumed by layer hens and potentially transferred to eggs.[101] Evidence suggests that carryover rates of aflatoxin in eggs may be higher than in other animal products such as milk.[101,102] One controlled study in Pakistan showed that feed contaminated with 50 μg or 100 μg of aflatoxin per kilogram of feed showed significant levels of aflatoxin in eggs, at 0.05 μg/kg and 0.07 μg/kg, respectively.[103] Another study in Brazil found a lower carryover rate: hens given 500 μg per kilogram of feed produced eggs with an average aflatoxin concentration of 0.10 μg/kg.[102] Still, this aflatoxin concentration in eggs is comparatively lower than what has been previously detected in the eggs of chickens fed maize-based diets, 0.66 μg/kg.[104] While heat processing of eggs may reduce *Salmonella* and *E. coli* contamination, it has little effect on the detoxification of AFB1 in egg.[103]

Environmental impacts of egg production

This review does not cover the expanse of environmental issues arising from industrial poultry production because the emphasis here is on egg nutrition among poor populations living in developing countries. In these groups, eggs are more likely to have been produced by smallholder farmers. In one review of livestock production in Brazil, India, the Philippines, and Thailand, the authors conclude that smallholders have less impact on the environment, but their "transaction costs" to minimize negative environmental externalities are higher than those for large farms. Therefore, incentives may need to be built into programs to support actions to abate problems. Household scavenging poultry systems described below have minimal environmental impact, particularly compared with the impact of other livestock, since they do not contribute to overgrazing, degradation of habitats, soil erosion, or depletion and pollution of drinking water sources.[105] Ammonia emission and other air quality problems,[106] antimicrobial resistance,[107] and eutrophication of surface waters[108] are among some of the environmental concerns associated with larger-scale poultry production and waste management. Strategies to mitigate these effects could be considered in different forms, where feasible, for small-scale production.[109]

HOMESTEAD CHICKEN-AND-EGG PRODUCTION

Homestead chicken-and-egg production can provide income for households, thereby helping to alleviate poverty and food insecurity, though evidence of the effects on nutritionally vulnerable groups in developing countries is minimal.[110–112] Households typically maintain a local chicken scavenging system with a flock of 5–20 birds (2–4 laying hens), with the birds scavenging for most of their feed during the day and roosting in trees or in the family home at night.[113] Poor women and children commonly raise chickens for income and sustenance. Among poor households in Africa, the low-input scavenging chicken system, before improvements, may provide 10–35% of the woman's income.[114–116] The income from poultry is often one of the few significant sources of income for women and is particularly important for covering expenses such as household emergencies, a health clinic visit for a sick child, the patching of a roof, or school fees.[95,115] Income from eggs is also used to purchase less expensive foods such as maize and cooking oil or other necessities like charcoal.[95,115,117]

Increasing egg production as a livelihood strategy: a first step out of poverty

Improving household scavenging poultry production is a practical and effective first step in alleviating rural poverty.[111,118] Poultry is the most common animal owned by the rural poor across Africa. For example, in Swaziland, 92.5% of rural households have poultry, while only 50% have cattle and 48% have goats.[119] Research in Africa has found that poultry production is one of the few and first mechanisms for asset accumulation in poor households.[118] Chicken flocks are developed to earn income to purchase goats or cows or to pay for starting a business.[118,120] A poor household can begin a scavenging system with the small investment of purchasing or, where possible, borrowing one hen. With minimal husbandry, that single hen, scavenging for its own feed (and utilizing the services of a village rooster), can produce a clutch of fertile eggs (10–12 eggs) in a few weeks, and a few surviving chicks from that clutch can triple or quadruple the number of laying hens within 6 months.[95,121] Within a year, it is possible for that household to have developed a flock of 9–10 laying hens, producing a dozen eggs per week. Within 18 months, the household could have a flock of 20 or more hens, providing two dozen eggs per week.

Feasibility of household chicken-and-egg production

Scavenging chicken production is an appropriate system for poor households, and production of eggs is practical for low-income families without access to refrigeration. Despite predation and diseases that cause high chicken mortality, scavenging systems are sustainable and, thus, ubiquitous throughout developing countries in Africa, Asia, and Latin America.[122] Egg production, which utilizes inexpensive local resources and does not require land ownership, is an activity available to poor households.[123] Chickens may graze along roads, on garbage around the village, and on agricultural waste of nearby fields. Raising chickens in a scavenging system is a very low-risk activity that converts insects, vegetation, and household garbage into nutritious eggs and meat. Considerable improvements in production can be made at the household level by applying basic husbandry practices, utilizing local resources, and utilizing low-cost technology such as the Newcastle disease (ND) vaccine.[95,124]

Compared with other livestock, poultry is small in size, rapid in food production, requires smaller quantities of feed, and is more efficient in converting limited feed resources to high-quality food.[123] Chickens have a short production cycle compared with cattle, hogs, or goats. They reproduce in a few months, growing from egg to chick to laying hen in 6 months.[95,125] Chickens are easy to raise and require little labor to produce. Women with household responsibilities, children, elderly, disabled, and chronically ill members of the household can care for chickens. Chickens consume pest insects and provide manure for fertilizing vegetable gardens or crops. As a consumer of garden waste and a provider of manure, they complement homestead high-nutrient vegetable gardens. In this system, net fencing may be used to keep chickens out of the garden, where they may damage seedlings or young plants.

Challenges and solutions in homestead chicken production

Poor practices in animal health and husbandry limit village chicken production and related benefits for households and small farmers throughout Africa, Asia, and Latin America. When unprotected, most village flocks typically will be decimated by disease and predation, which reduces the willingness of households to invest in making improvements.[113,126] The primary challenges to raising a household chicken flock are prevention of disease in a scavenging system, lack of night shelters and nest boxes (coops), poor management of flocks and eggs, poor supplemental feed, low chick production, and limited access to expert advice, ND vaccine, and veterinary products.[127–129]

Prevention of disease is the most difficult challenge to improving household and village chicken production. ND causes mortality as high as 80% among village chicken flocks in rural communities in Africa, Asia, and Latin America.[110,113] Improvements in poultry husbandry will likely fail to improve production if ND vaccination is not implemented first. Other common disease problems in scavenging systems are internal and external parasites, fowl pox, and infectious bursal disease,[126] but none of these other ailments have the devastating impact of ND. ND can be controlled by the proper use of an inexpensive thermotolerant vaccine (produced by many national veterinary laboratories).[130] Maintaining effective vaccination programs requires educating local veterinary suppliers about cold chain management and handling of vaccines, as well as efforts to resolve issues of vaccine production and distribution in remote rural areas.

Adequate housing and flock management are other common challenges. Providing a night shelter enables good management. With a coop, it is easy to handle birds daily and check them for parasites or signs of disease, to collect all eggs and manage egg production, and to track which birds are good producers and which should be culled (sold or consumed). Low-tech chick brooders can also be constructed from local materials and heated from small quantities of charcoal or burning cow dung.[95] Predator-resistant coops combined with training and the adoption of basic egg, chick, and hen management practices will increase chicken-and-egg production at the household level.[95,121]

Poor feed resources for supplemental feeding and high chick mortality may be another limiting factor in the scavenging system.[113,126] While scavenging chickens may forage for most of their diet, they often have diet deficiencies. The productivity of scavenging chickens can be improved with supplemental feeding, particularly if chicks and laying hens are supplemented. Identifying local sources of crop and food wastes that can serve as economical feed is an important component of husbandry for village poultry.

Through holistic short extension courses (2 or 3 days), rural residents can learn about vaccination, coop construction, egg and chick management, supplemental feeding, and strategies for accessing markets for their products.[95,128,131] In addition to training, communities must have access to ND vaccine, drugs to treat for parasites, and technical advice. Typical unvaccinated household indigenous flocks in Africa range from 5 to 15 birds.[113] Laying hens of these flocks lay 40–60 eggs per year. The implementation of ND vaccination and modest husbandry improvements may increase the number of hens threefold and total egg production severalfold at the household level. Sustainable improvements can be made with local birds in low-risk scavenging systems, yielding substantial improvements in small-farm chicken-and-egg production.[119,124,132,133]

CONCLUSION

Eggs show tremendous potential for improving maternal and child nutrition in developing countries, though few intervention studies have been performed. Evidence of the nutritional value of eggs is plentiful. Able to entirely support early growth and development, eggs offer a holistic package of nutrients. They are a rich source of EFAs, choline, vitamins A and B_{12}, and bioavailable iron, zinc, and iodine, primarily the nutrients in which poor and at-risks populations are known to be deficient. The current use of eggs as complementary food for young children varies regionally. Latin American countries, on average, showed higher proportions of children between the ages of 6 and 24 months consuming eggs than Asian and African countries. There were some countries, such as India and several in Africa, in which the prevalence of egg intake was extremely low among young children. Cultural beliefs about egg digestibility or cleanliness, as well as the affordability of eggs, both real and perceived, may inhibit consumption. Recent evidence mitigates concerns about allergies and cholesterol in association with dietary egg intakes.

There are economic advantages to increasing egg production and consumption in poor communities, from both the consumer and producer perspectives. In terms of access to high-quality foods worldwide, the unit price of eggs is lower than all other animal-source foods except milk.[134] Homestead chicken-and-egg production also shows great potential to provide livelihood and health benefits to very poor, rural populations. With appropriate strategies in place, such as ND vaccination, predator-resistant coop construction from local materials, use of supplemental feeds from agricultural wastes, and holistic extension courses, among others, this model can result in increased egg production for both consumption and generation of income. There is some evidence of positive impacts of behavior change communication strategies to encourage the use of eggs in the diets of young children, but very little information about egg consumption and interventions in maternal settings is available.

Based on the findings of this review, further research is recommended to test the efficacy of dietary egg intakes to improve maternal and child nutrition in developing countries. Effectiveness studies are also needed to examine interventions that overcome economic, educational, and cultural barriers to intake. Policies that facilitate trade and marketing of eggs at reduced costs, support homestead egg production, and highlight the nutritional value of eggs for vulnerable populations might be implemented. The egg agenda proposed here aligns with the Millennium Development Goals (The United Nations Millennium Development Goals. http://www.un.org/millenniumgoals/) to eradicate extreme poverty and hunger, reduce child mortality, and improve maternal health. Eggs may be a locally available and feasible option for poor households, with uncracked potential to address the most salient issues of undernutrition.

Acknowledgments

The authors would like to acknowledge the contributions of Monica Kothari, from PATH/ICF International, who provided data from MEASURE Demographic and Health Surveys for the regional comparisons of egg consumption. As well, the authors acknowledge the considerable effort given to this project by research assistants Jacqueline Bailey Mounce and Kate Clitheroe at Washington University in St. Louis. All authors have contributed significantly to the work's conception, design, and data interpretation; all have participated in the writing and critical review of the literature to establish ownership of the intellectual content.

Funding. The authors have no funding to declare.

Declaration of interest. The authors have no relevant interests to declare.

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