Chapter

Improving the Cognitive Development of Children in Rural Areas as Development Tool

Jacob Alhassan Hamidu, Charlisa Afua Brown and Mary Adjepong

Abstract

Good health is a crucial requirement for every child for proper growth and development. To increase their future prospects the exact nutritional intervention is needed to boost the thinking and self-confidence of children. Adequate levels of omega-3 essential fatty acids are vital for children during pregnancy, breastfeeding, and few years post-weaning. This is not just for their perfect growth but including their cognitive development. Poverty levels continue to be high in rural areas and there are nutritional interventions that can be used to reverse the trends. However, omega-3 fatty acids, known to have a greater impact on brain development are not cheap and available in forms that are accessible by the rural poor. With the many complications attached to a rural lifestyle, little is known about culturally accepted local sources of omega-3 fatty acids. Therefore, alternative sources of nutritional intervention including the provision of eggs enriched with appropriate fatty acids, which are readily available, accessible, cheaper, and culturally accepted should be explored for children.

Keywords: Infants, children, rural areas, nutrition, cognitive development, omega-enriched eggs

1. Introduction

Malnutrition is an increasing health problem among children in most developing African countries, especially among rural infants [1]. These young children are most vulnerable due to their high nutritional requirements for growth and development. This is on the backdrop that over 60% of the world population in Africa live in rural areas [2]. In many poor communities in Africa such as Ghana, a severe form of malnutrition called Kwashiorkor is common. Malnutrition is problematic because many children younger than 5 years in rural areas are exposed to multiple challenges including the high poverty situation of parents and unstimulating home environments. This can affect feeding practices. As a result, these children are disadvantaged leading to malnutrition, poor health, and early childhood stunting. These conditions detrimentally affect their cognitive, motor, and social–emotional development. The effects extend into poor cognitive and educational performance.

Children who perform poorly in school, have attention deficit, have poor future prospects, and subsequently have low incomes; as adults, they exhibit poor cognitive utility living lives below their intellectual capabilities. Attention problems resulting from malnutrition-related challenges persisting to adulthood are an indication of the continuation of poor brain development over the life span of a person. Infantile malnutrition may have long-term effects on attentional processes for over 40 years after its initial establishment. Once established it is difficult to reverse even with excellent long-term nutritional rehabilitation and provision of independent socioeconomic conditions in childhood and adolescence. The challenge with malnutrition, poor cognitive development, and related poverty carry over effects continues to adulthood leading to poor care for children, thus contributing to the intergenerational transmission of poverty and poor standard of living [3–5]. The objective of this chapter is to explore alternative nutritional sources to increase the cognitive development of children in rural areas in Africa, especially Ghana.

2. Factors influencing brain development in children

Historically, higher IQ children are found in urban areas. It has been observed that although both low-income rural and low-income urban children show working memory deficits compared with their high-income counterparts, the low-income urban children exhibited symmetrical verbal and visuospatial working memory deficits compared to their high-income urban counterparts. These results suggest that different types of poverty are associated with different working memory abilities. Memory deficiency is predominately enhanced in rural locations where children are deprived of good nutritional benefits. It is estimated that over 200 million children under 5 years are not fulfilling their developmental potential in south Asia and sub-Saharan Africa, which have more nutritional deficiencies especially in rural areas [6].

For the same level of socioeconomic status in assessing executive functions and non-verbal intelligence performance in 5-year-old children, children in rural settings performed consistently worse than children in urban settings. Both parents' educational level and poverty greatly accounted for poor cognitive functions. In the US lower omega-6 to omega-3 ratios are associated with eating healthy diets in both adults and children. However, adults with a college degree showed much lower ratios than those without a college degree. The situation depicts the impact of knowledge level, financial ability, and exposure to education on eating habits, which are more experienced in parts of Latin America and Sub-Saharan Africa [6, 7]. In China, the urban community setting showed a significant protective effect on cognitive impairment. Cognitive underdevelopment was often prevalent in underprivileged communities and these are poorly addressed in rural settings. It is stated that malnutrition early as far as 3 years has an association with poor cognition at age 11. This prompts the need to promote early childhood nutrition and address factors affecting nutritional choices since they enhance long-term cognitive development and school performance, especially in children with potential for multiple nutritional deficits as may happen in rural areas [8].

2.1 How rural children develop lower cognition level

Cognition is defined as the processes by which an individual processes information through skills of perception, thinking, memory, learning, and attention. There is more evidence that connects improved nutrition and optimal brain function, with studies showing that brain development is faster in the early years of life compared to the rest of the body. The conditional availability of breast milk early in life may account for faster brain development. However, brain development is affected by quality, timing, and the regional requirement for a particular nutrient at that time in the brain. Nutrients provide building blocks that play a critical role in cell proliferation, DNA synthesis, and neurotransmission, and hormone metabolism. Therefore, children that are malnourished through the mother may be at higher risk [7, 8].

Urban children are taller and heavier than rural counterparts in almost all low-income and middle-income countries. The urban–rural difference is largest in Andean and some central Latin American countries such as Peru, Honduras, Bolivia, and Guatemala. A similar trend in some African countries including Niger, Burundi, and Burkina Faso; and in Vietnam and China. The disparity between urban and rural children's growth is clear with urban children in China, Chile, and Jamaica looking taller than their rural folks. All over the world, the heaviest children live in cities and the most underweight in rural areas. Between 1985 and 2011, the urban advantage in height fell in southern and tropical Latin America and South Asia, but changed little or not at all in most other regions. The urban–rural weight differential also decreased in southern and tropical Latin America, but increased in East and Southeast Asia and worldwide. Overall, the weight gain of urban children outpaced that of rural children [9].

While listing other factors such as poor health care and improved access to affordable stable food and its supply as the major contributing factors to poor cognitive development in rural areas, the quality of nutrition was largely lacking in rural areas. Here, the foods lack adequate amounts of limited nutrients such as proteins, fatty acids, and vitamins. In Ghana, children with the highest levels of total n-3 and docosahexaenoic acid (DHA) were three and four times, respectively, more likely to pass at least one condition of the dimensional change card sort (DCCS) test of executive function than those with the lowest DHA levels. The results of this study indicate an association between n-3 FAs and high-level cognitive processes in children two to six years of age, providing an impetus for further studies into possible interventions to improve essential fatty acids (EFA) status of children in developing countries [10]. The effects of docosahexaenoic acid/omega-3 long-chain essential fatty acid on externalizing behavior are more mixed. Other micronutrients known for their impact on brain development and cognition include zinc, iron, vitamin B, and protein deficiencies, which lead to low IQ and later high antisocial behavior in children. However, the more indicators of malnutrition there is, the greater the antisocial behavior resulting from children. From

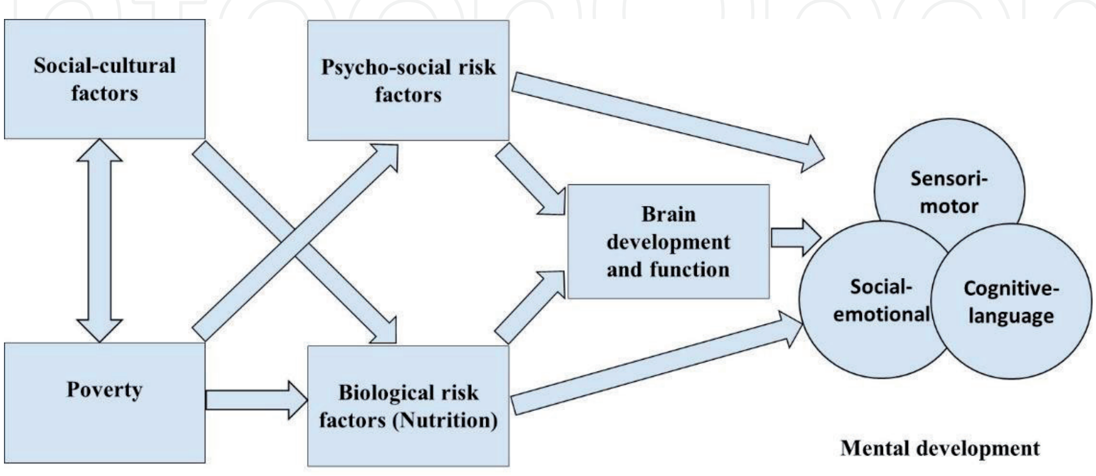

Figure 1.
Nutritional and social factors influencing brain development (Source: Osendarp [11]). Many factors contribute to appropriate development of children and in turn impacts on sensory, social, emotional and cognitive performance of children. However, nutritional factors are easier are easier to address but they must be culturally, economically and socially accepted to make impact in rural communities.

animal and human findings, it is clear that malnutrition impairs neurocognitive functioning by reducing neurons, alternating neurotransmitter functioning, and increasing neurotoxicity. The neurocognitive impairments predispose to externalizing behavior. Poor nutrition contributes to the development of child behavior problems (**Figure 1**) [11–13].

3. Relationship between omega-3 fatty acid and children brain

The growth and development of children is key in developing countries mostly concentrated in sub-Saharan Africa. Rural children are poorly malnourished and this is not only affecting their growth but also cognitive ability. According to Akinwumi Adesina, President of the African Development Bank in the 2017 Global Nutrition Reports, "Nourishing the SDG's", he said "Africa's economic progress is being undermined by hunger, malnutrition and stunting, which cost at least US$25 billion annually in sub-Saharan Africa, and leave a lasting legacy of loss, pain and ruined potential". He continued, "stunted children today lead to stunted economies tomorrow". Hence poor health of children both born and unborn can have strong implications on personal and national growth. The causes of malnutrition are in parts directly related to inadequate dietary intake. Other factors include diseases, household food security, maternal and childcare, health services, and the environment. While most nutrition interventions are delivered through the health sector, non-health interventions such as appropriate dietary or nutrient type can also be critical. Actions should target the different causes to reach sustainable change, which requires a multi-sectoral approach [14].

Adequate levels of omega-3 essential fatty acids are vital before conception, during pregnancy, and during breastfeeding to ensure a perfect start to life. Mothers need to produce not just enough vital DHA and EPA for themselves and their own body but also enough for the new life and vital organs of their baby too, particularly the brain, nervous system, and eyes. Omega-3 long-chain polyunsaturated fatty acids have been observed as important constituents of young and maturing brain cells of children and therefore are considered crucial for brain development in utero and early infancy. In children older than 2 years of age, epidemiological evidence suggests an association between psychiatric or neurodevelopmental disorders and omega-3 fatty acid deficiencies. In neonates, a deficiency is associated with visual impairment, abnormalities in the electroretinogram, and delayed cognitive development [10, 15, 16].

There are three types of omega 3 fatty acids (alpha-linolenic acid (ALA), eicosapentaenoic (EPA) acid, and docosahexaenoic acid (DHA), each of which is needed in the human diet because of their unique beneficial qualities on health and brain development in children. The ALA is carried by plants and is efficiently converted to the EPA in human tissues. The capacity to up-regulate ALA conversion to DHA in women is assumed important for meeting the demands of the fetus and neonate during pregnancy [17]. However, most pregnant women and children in rural areas may not be getting enough omega-3 fatty acids because the major dietary source that contains n-3, which is seafood is not available. Seafood is restricted to coastal areas. On the part of rural people, their purchasing power restricts them to less seafood and in urban areas, the major restriction is two servings a week. These fatty acids are especially critical during pregnancy for the development of the baby's brain, nervous system, and retinas. Studies have shown that pregnant women whose diets were higher in docosahexaenoic acid had offspring with higher IQ scores while infants who did not get enough omega-3 fatty acids from their mothers during pregnancy are reported to be at risk of developing vision and nerve problems. Children with attention-deficit/hyperactivity disorder (ADHD) may have low levels of certain essential fatty acids (including EPA and DHA) [18]. In a clinical study of nearly 100 boys, those with lower levels of omega-3 fatty acids had more learning and behavioral problems (such as temper tantrums and sleep disturbances) in comparison with boys with normal omega-3 fatty acid levels. All these are possible because omega-3 fatty acids improve metabolic responses such as low-density-lipoprotein (LDL) oxidations of blood glucose and these have direct functions on the brain [19].

3.1 Omega3 fatty acids intake of children in Africa and Ghana

Omega-6 and omega-3 fatty acids (FAs) and their ratio have been shown to affect cognitive function in children and older adults. It is expected that most children would consume at least the recommended amount of alpha-linolenic acid (ALA; omega-3) for their age and gender without consuming high amounts of linoleic acid (LA; omega-6). However, children often do not consume sufficient eicosapentaenoic acid (EPA; omega-3) and docosahexaenoic acid (DHA; omega-3), which form the bulk of the directly usable form of omega-3 fatty acids needed for brain development. Currently, it is not stated what the daily intake of omega-3 FA is in a typical African population by country but there are spatial data for certain locations. However, in developed countries, there are data to show intake. The average American consumes about 1.6 grams of omega-3 FA daily and about 1.4 grams of this comes from ALA, while 0.1-0.2 grams from EPA and DHA. Additionally, the American Heart Association recommends that healthy adults eat fish at least twice weekly because of the large amounts of omega-3 FA. The World Health Organization (WHO) also recommends a daily EPA and DHA intake of 0.3-0.5 grams and a daily ALA intake of 0.8-1.1 grams [20].

The overall omega-3 fatty acid intake of children in three different geographical communities in South Africa has shown that daily intakes are low in children from all communities studied. The median combined intake of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) was 50, 55, and 3 mg a day in the 3 communities, which are very far below the typical recommended intake between 100 and 200 mg per day for children from 2 to 6 years. It is general to see higher consumption levels of omega-6 fatty acids rather, which is known to suppress endogenous production of EPA and DHA from ALA (alpha-linolenic acid). In Ghana pregnant and nursing mothers often consume a lot of melon seeds (Neri and Egushi) with the sole aim of increasing their breast yield and quality. However, it has been demonstrated that the two seeds rather contain higher levels of omega-6 fatty acids and non-existent levels of omega-3 fatty acids. The largest nutritional benefit derived from the seeds is the higher content of amino acids, which could increase children's general development but may not have a greater impact on cognitive development [21–23].

In the Gambia, omega-3 intake of children below 36 months was as low as 140 mg per day compared to children in Britain. However, there was no variation in the omega-6 intake. Additionally, the growth of children by body weight in Britain was superior from infancy to 36 months compared to children in the Gambia, emphasizing a deficiency in omega-3 fatty acids in supporting children's growth and development both maternally and after weaning up to 36 months in a typical developing country. In several other Africa countries including Nigeria, Congo, South Africa, Burkina Faso, and Egypt there is evidence of lower maternal milk omega-3 levels, which appears to emphasize generally the lower omega-3 intake in children chronicled so far. The lower omega-3 intake is reflected in the diets taken by these people, which have higher amounts of omega-6 rather than omega-3 fatty acids [24].

In Ghana especially Northern Ghana, often characterized by increased poverty, the diets of children are mainly from cereals and fruits, with the intake of fats and proteins below adequate levels. In characterizing for whole-blood fatty acids levels of Northern Ghanaian children, specifically at Savelugu-Nanton district and to assess the association between FA levels and growth parameters, it was reported that a high level of Mead acid levels, a type of omega-9 fatty acids was evidence of essential fatty acids deficiency. Besides, the level of stunting in children was as high as 29%. This high level of stunting was also noticed along with significantly low DHA, total n-3, and the omega-3 index in stunted children compared to non-stunted children [25]. In a similar study, with children in southern Ghana of the same age, residing in communities in the Upper Manya Krobo district the blood omega-3 FA levels were rather significantly higher while omega-6 FA levels were lower compared to the previous study [26].

The mean level of DHA and the omega-3 index, for example, were 2.62% and 4.55%, respectively in the northern Ghana population compared to 5.09% and 8.03% in the southern Ghana population. Similar to the Mead acid level, this was lower indicating a lower EFAD compared to the Northern children. The disparity was due to this community's high consumption of fish and seafood compared to Northern Ghana children accounting for lower stunting. The proximity of the southern population to a fishing community could have accounted for the availability of fish as the major supplier of omega-3 FA rather than affordability, with both indicators being problematic in most rural communities. It appears there is a higher rate of EFA deficiency in the northern compared to the southern children. Comparative observation showed the southern children in this location also described as a fishing community had similar or higher omega-3 index than children in some developed countries. It is therefore clear from the two types of research that children in northern Ghana and by extension children in rural communities located far away from fishing vicinities were more at risk of not meeting their omega-3 FA need. Therefore, any intervention project should well focused on where there is a need for omega-3 FA supplementation. Since the above studies did not correlate the omega-3 measurements to cognition, a more detailed data collection of such a relationship was recommended [25, 26].

3.2 Bridging the gap in omega-3 fatty acids intake in children

Marine fish such as mackerel, salmon, sardine, herring, and smelt, both fresh and dry are excellent sources of EPA and DHA and influences the total available omega-3 fatty acids in diets greatly. Similarly, plant seeds and oils such as flaxseed oil, perilla oil, canola oil, soybean oil are good sources of omega-3 fatty acids, especially ALA but most of these seed/oils are not tropically available and therefore are not known in rural areas of most African countries. Sources such as Soybeans, sunflower, and palm oils contain varying quantities of omega-3 fatty acids but have large quantities of omega-6 fatty acids [27].

In Urban areas, there are fish capsules available in stores that could be taken to provide children with omega-3 FA and increase development. However, per some assumptions, rural people and people living in most developing countries will less likely accept capsule supplements due to various beliefs and cultural systems. It must be noted that the above sources of omega-3 FA are only given to children when they above 2 years in most cases. Therefore, providing omega-3 FA in eggs has been proposed in various circles as an alternative to fish sources. This is because they will find it to be more natural as they may not think about the deep scientific work done in incorporating the omega-3 FA into the eggs but they will know that egg is produced when feed is given to chickens and this is a natural process of producing eggs [28]. In developing countries, it is always the norm to increase food intake in rural areas and not necessarily food quality. However, concerns are rift on the quality of food because the levels of omega-6 FA are usually high in Africa foods. Therefore, new approaches to developing quality intake are long overdue. The idea in this chapter includes the exploration of the nutritional enrichment of eggs with omega-3 fatty acids, which will be largely accepted by rural folks. Even in a developed country like the USA, it has been observed that overall, omega-3 fatty acids intake as supplements was low among individuals with lower educational attainment and income levels. Many people were also at higher risk of lower omega-3 fatty acids supplements and fish intake with people in such disadvantaged positions [28]. This could be worse in rural areas of Africa where the family fish is rationed during meals. While supplemental use increased EPA + DHA intake only 7.4% of individuals consistently took the supplements. Additionally, daily supplementation of ≥450 mg DHA + EPA per day increased omega-3 index to >6%, which is described as a more likely show of efficacy on cognition in children and adolescents [29]. The Omega-3 index assesses the omega-3 status by analyzing the erythrocyte fatty acids, at least longer-term intakes over approximately the previous 120 days. This omega-3 index was proposed by Harris and von Schacky to reflect the content of EPA + DHA in erythrocyte membranes expressed as a percentage of total erythrocyte fatty acids [30].

3.3 Omega-3 eggs enrichment efforts in Ghana and Africa

The assembling on a least-cost basis a poultry layer diet with the inclusion of omega-3-fatty acid source has been explored at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, to produce eggs, which will be cheaper than other sources of omega-3 fatty acid sources in increasing the brain development of children in rural areas and sustain healthy living. Between 2014 and 2016, this study was successfully conducted in Ghana with the incorporation of omega-3 fatty acids in eggs through the diets of laying chickens in Ghana, the first in the Sub-Saharan Africa region. The Grand Challenges Canada, saving brains grant for research, supported this proof of concept. The technique was accomplished through poultry production techniques of feeding poultry diet formulated with the inclusion of flaxseed oil, a concentrated source of the omega-3 fatty acids group called ALA, which appreciably can be converted to EPA and DHA in infants that are easily usable by the body [31]. The eventual fatty acids deposited in the eggs were analyzed and proven with laboratory procedures through gas chromatography technology. Upon completion of the research, it was realized that the control diet which did not contain flaxseed because of the inclusion of fishmeal in the diet contained 466 mg per 50 g egg while the 3% flaxseed oil inclusion in poultry diet treatment together with some fishmeal yielded 1,206 mg omega-3 fatty acids per 50 g egg. Considering that, the research yielded more omega-3 fatty acids even with the control diet there is a lot of progress made in ensuring adequate nutrition for rural children. The idea is on the premise that the amount of omega-3 varies with the number of foods containing omega-3 s that are eaten by hens but must be bioavailable to humans. The target is to make these eggs available in rural areas. Interestingly, in this study, there was a high yield of ALA compared to EPA and DHA. In children above 2 years, it is understood that the conversion rate of ALA to EPA is moderate but very limited to DHA. However, the higher the level of ALA and lower the level of LA, the increase in the conversion of ALA into EPA or DHA, with the conversion more dependent on absolute amounts but not their ratio [32]. Interestingly, there is evidence that the local, indigenous people of Africa seemed to have retained the genetic ability to activate the necessary dehydrogenase and elongation enzymes to make EPA and DHA from the readily available ALA substrate, which makes the above study a potential solution to the omega-3 FA deficiency for Ghanaian and Africa children [33].

4. Eggs as alternative carrier of omega-3-fatty acids in rural areas

The egg is one of the cherished sources of nutrients in human food and it plays a vital role in a healthy life. It has low-calorie content and supplies most nutrients including proteins when consumed. A 60 g egg contains 61.5% (36.9 g) albumen, 29% (17.4 g) yolk and 9.5% (5.6 g) shell. A 60 g chicken egg contains about 5.5 to 6 g lipids, which is found in the egg yolk [34]. The fatty acid profile of a hen's egg shows that 44% of the lipids in eggs are MUFA, followed by 29% saturated fatty acid and 11% PUFA [35]. Conventional hen diets result in eggs with a n:6: n:3 ratio of about 13:1, much higher than recommended for optimal health [36]. However, an enriched egg can provide upwards of 500 mg total n:3 PUFA, which may contain up to 290 mg of combined EPA and DHA. Both n:3 and conventional eggs contain the same amount of energy, protein, saturated fat, and monounsaturated fats but the n:3 eggs contain more LA, AA, ALA, DHA when compared with conventional eggs. On average, a commercially available n:3-enriched egg contains about 75 mg DHA for an egg from a flax-fed hen, and 125 mg DHA from a hen fed both flaxseed and fish oil (**Table 1**) [37].

A fortified egg has the unique advantage of combining almost all the primary nutrients from animals for humans. These include innately providing the highest quality protein and amino acid proportions, fats and essential fatty acids, vitamins, and minerals. Eggs also have a unique capacity to concentrate added essential nutrients and phytonutrients and effectively deliver them with high bioavailability [19]. Additionally, eggs are highly acceptable among rural folks and therefore its substitution for nutrients supplements for children is highly recommended. Besides

Nutrient	N:3 Egg	Conventional Egg2
Energy (calories)	70	70
Protein (g)	6	6
Total fat (g)	5.0	5.0
Saturated fat (g)	1.5	1.5
Monosaturated fat (g)	2.0	2.0
Total n:6 fatty acids(g)	0.8	0.6
Linoleic acid(mg)	6405	540
Arachidonic acid(mg)	305	80
Total n:3 fatty acid (g)	0.43	0.1
Alpha-linoleic acid (mg)	1745	31
Eicosapentanoic acid (mg)	175	1
Docosapentanoic acid (mg)	105	4
Docosahexanoic acid (mg)	1085	344
Cholesterol (mg)	195	195

Source: Gillingham et al. [12].

Table 1.
Nutrient content of enriched and conventional eggs.

eggs are cheaper sources of concentrated nutrients. In the past, the WHO has recognized the need to improve the process by which health-related recommendations are developed including nutrition using the best available evidence. With this, the WHO Nutrition Guidance Expert Advisory Group was formed with experts from WHO Advisory Panels and other experts in the fields of epidemiology, nutrition, public health, pediatric medicine, and program implementation. We recognize that nutritional cognitive development innovation should provide a solution for children and must follow proper guidelines [38]. An additional proposal from the WHO includes adopting priority nutrition outcomes such as complementary feeding counseling and active feeding, growth monitoring and promotion, and supplementary feeding or food-based interventions. That is why we have spent the time to provide proof that it is possible to intervene in cognitive retardation with nutritionally fortify eggs, which will complete the protein and other essential nutrients in supporting children's development. This is because the special functions of the brain are reflected in a higher need for nutrients such as choline, folic acid, iron, zinc, and special fats (e.g. gangliosides, sphingolipids, and docosahexaenoic acid (DHA)) and we emphasize the essential fatty acids. For eggs enriched with omega-3 fatty acids, the health advantages include high antioxidants levels, due to high n-9 monounsaturated fatty acids (MUFA) or n-3 polyunsaturated fatty acids (PUFA), with lowered n-6 PUFA, and n-6: n-3 ratio over regular eggs [8].

4.1 How much omega-3 is required by children through eggs

For children between 6 months to 8 years the total ALA omega-3 fatty acids need is between 0.5 g to 0.9 g per day [39]. In the research at KNUST, a 50 g egg enriched with 3% flaxseed oil provides 1.2 g of the total omega-3 per day with a high level of ALA in addition to EPA and DHA. Besides, the majority of the omega-3 fatty acids contain other types of omega-3 fatty acid eggs that are readily available for direct utilization by children for improved health using the enrichment procedure adopted, compared to available enrichment procedures that use only flaxseed or algae that enriches mostly ALA. Increasing omega-3 eggs intake of this local enrichment intake for a period of weeks to months could result in an increase in the proportion of eicosapentaenoic acid (EPA; 20:5n-3) in plasma lipids, in erythrocytes, leukocytes, platelets in children and in breast milk with potential to increase newborn health [40].

Protein intake combines with omega-3 FA intake for child growth and development. An average egg contains about 6–7 grams of proteins. However, the protein content depends on egg size. The average protein requirement for a child's development ranges from 1.12 g/kg/day at age 6 months to 0.74 g/kg/day at 10 years, with a small decline towards the adult value thereafter. The corresponding values for the safe level are 1.43 g/kg/day at 6 months and 0.91 g/kg/day at 10 years. These values show that just one 50 g egg a day will provide over 5 g more protein for a child per day [41]. This means eggs contain so much protein for a child's development and is a cheaper source of protein. So just one egg in 5 days is far enough and village people can afford this. So considering the wastage of protein/omega-3 in the human metabolism pathway, one egg for 2 days at most is sufficient for a child's development if other sources are excluded. Out of 43 countries in sub-Saharan Africa, only nine countries have an average consumption of eggs that is higher than 2 kg while in most of Asia and the Americas, people eat at least twice that amount, and in Japan, it is 19.1 kg. Expanding the poultry business using eggs will increase production because consumer perception will change. The potential increase in egg intake will greatly affect the egg value chain (grain producers, hatcheries, feed manufacturers, poultry farmers, veterinary stores, and egg sellers). This happened in South Africa in 2010; an increase in egg consumption led to higher prices, production, and jobs [42].

In 2015, the MDGs expired, yet average nutritional problems in Ghana were still high with about 20% of children being stunted, 9% is wasted and 14% being underweight. The approaches used in the MDGs included vaccinations, NGO interventions, and aids. However, Ghana did not appear to achieve MDG 4 (reducing child mortality at end of 2015) due mostly to hunger and poor nutrition (MDG 3). According to the World Food Programme, eradicating hunger and malnutrition is one of the great challenges of our time, and not having enough – or the wrong food causes suffering and poor health, as well slows progress in education and employment.

The project of enriching eggs with omega-3 FA has the potential to meet the now SDGs 1 to 5 including no poverty, zero hunger, good health, and well-being, quality education, and gender equality respectively in very vulnerable people in our society especially women and children (unborn and children under 5 years). There is considerable evidence that the DHA content of the maternal diet is the most important determinant of the amount of DHA secreted in milk, which increases children's health. Therefore, it is no surprise that infants fed a DHA-fortified formula have better eyesight than infants fed a formula without it. However, these nutrient supplements are not available to rural parents and make them a vulnerable population. The greater portion of the diets of rural people in Ghana similar to the Western population contains greater amounts of omega-6 fatty acids (oil palm, starchy foods, overcooked vegetables) leading to poor health [43]. By eating eggs especially the omega-3 fortified eggs it will also give them a good balance of omega 3 to 6 ratio. With the focus on children, and women living in rural areas there is a greater potential to provide quality nutrition and health care.

4.2 Omega-3 egg impacts the egg value chain in Africa

The idea of developing the omega-3 eggs through the feed of poultry layers will expand the egg value chain. This includes enhancement of the activities of operators of breeder farmers (layer breeder flocks to produce fertile eggs for a hatchery), hatcheries, commercial egg producers (have layer flocks to produce table eggs), egg marketers, feed millers and feed processors, or feed ingredient dealers and primary crop farmers, veterinary drug dealers and consumers of the eggs. Eggs are also useful to many households, especially rural communities that have bigger malnutrition challenges. In Ghana specifically, the Government school feeding program, free senior high school program, and various public institutions including hospitals need eggs as higher immune booster especially with the COVID 19 pandemic where patients need to eat good quality food to increase their immune system. The omega-3 egg value chain can address the marketing challenges of egg farmers and increase its intake in the whole Sub-Saharan Africa Region and Africa.

NB: It can be noted from the **Table 1** above that both omega-3 enriched eggs and conventional eggs have the same amount of energy, protein, total fatty acids, saturated fatty acids, monosaturated fatty acids and cholesterol. These components of the egg are responsible for energy and protein to enhance growth of children, but may not necessarily increase brain development to increased cognition and future prospects of children. Children need not only to grow but must undergo the proper physiological and psychological developments to make them contribute positively to societal development. The enhancement of cognition and its mechanism of brain function has not being studied very well from the egg nutrient point of view. Since omega-3 fatty acids and the omega-3:omega-6 fatty ratio are known to increase brain development they should be well explored. It can enhance cognition and by extension development of children. The most impact can be experienced in rural communities. The enrichment of eggs in this instance, which leads to increased omega-fatty acids and it major components ALA, EPA, DHA and LA by larger folds is a cheaper alternative to increased brain development, child development and cognition development in rural communities. The production of omega-3 fatty acids eggs is a much cheaper, convenience and culturally accepted method compared to medical administration of omega-3 fatty acids supplements to children to increase development.

5. Conclusions

Omega-3 enriched eggs is proposed to supplement the diets of school-going children below age 6. Additionally, embarking on a public health campaign on the health benefits of eggs, engaging governments to use innovative methods to engage stakeholder to increase the intake of eggs for nutritional improvement of children in rural areas. The prospects of the omega-3 fatty acids include increasing academic performance and future prospects of rural children. In addition to the above, increased production and consumption of eggs, especially with the branding of eggs through omega-3 fatty acids fortifications in the developing countries will increase food and nutrition security, and the development of children in rural areas. Besides, eggs are inexpensive source of high-quality protein, essential vitamins, and minerals that are needed for a healthy diet and a healthy life and important for the nutrition of growing children, as well as being culturally acceptable. The current suggestion could increase business, create jobs within the egg value chain, and open opportunities for all stakeholders in health, agriculture, government, and philanthropic organizations, and be used as a tool for increasing rural development.

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Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

Aims of the chapter

This chapter shows how infants and children below 5 years are disadvantaged in rural areas. They are also deprived of appropriate and adequate nutrition. This affects their wellbeing, cognitive development and future prospects. The chapter is a form of communication to opinion leaders and stakeholders to address the long-term effect of infant nutrition in rural areas, especially in Sub-Sahara Africa on cognition and how this lingers on into adult life. Moreover, to be useful, the chapter advocates adequate nutritious food, which is eggs and presents a calculated strategy with research proven omega-3 fortified eggs to reverse memory deficits in children during pregnancy and in breast feeding children. Therefore, the ability to perform excellently in children from rural communities will depend on traditionally approved and acceptable nutritional strategies, which can increase sustainable livelihoods in rural communities. The book chapter is a suggested solution to malnutrition, poverty reduction and livelihoods improvement as sustainable development plan to solving malnutrition in rural children.

Key points

In this book chapter there is strong demonstration that:

By enriching the diet of layer birds with 3% flaxseed oil, there is an increase in specific fatty acids that make up omega-3 and omega-6 fatty acids, resulting in eggs high in omega-3 fatty acids.

Total omega-3 fatty acids were 2.54 times higher in the 3% flaxseed oil eggs than the 0% flaxseed oil eggs. However, the feed cost in producing omega-3 eggs by incorporating 3% flaxseed oil was also 2.25 times higher.

In terms of taste, acceptability, smell of the yolk and texture of the egg yolk, the taste panelist did not notice any difference between the flaxseed oil eggs and the fishmeal eggs, or those with no flaxseed oil included in the diet.

Author details

Jacob Alhassan Hamidu[1*], Charlisa Afua Brown[2] and Mary Adjepong[3]

1 Department of Animal Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

2 Kwadaso Agricultural College, Kumasi, Ghana

3 Department of Biochemistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

*Address all correspondence to: jahamidu.canr@knust.edu.gh

References

[1] Abdel Wahed WY, Hassan SK, Eldessouki R. Malnutrition and its associated factors among rural school children in Fayoum governorate, Egypt. Journal of environmental and public health. 2017 Oct 23;2017

[2] Amzat J, Razum O. Rural Health in Africa. InTowards a sociology of health discourse in Africa 2018 (pp. 109-124). Springer, Cham. https://doi.org/10.1007/978-3-319-61672-8_8

[3] Galler JR, Bryce CP, Zichlin ML, Fitzmaurice G, Eaglesfield GD, Waber DP. Infant malnutrition is associated with persisting attention deficits in middle adulthood. The Journal of nutrition. 2012 Apr 1;142(4):788-94. https://doi.org/10.3945/jn.111.145441

[4] Galler JR, Bryce CP, Zichlin ML, Waber DP, Exner N, Fitzmaurice GM, Costa PT. Malnutrition in the first year of life and personality at age 40. Journal of Child Psychology and Psychiatry. 2013 Aug;54(8):911-9

[5] Grantham-McGregor S, Cheung YB, Cueto S, Glewwe P, Richter L, Strupp B, International Child Development Steering Group. Developmental potential in the first 5 years for children in developing countries. The lancet. 2007 Jan 6;369(9555):60-70.

[6] Tine M. Working memory differences between children living in rural and urban poverty. Journal of Cognition and Development. 2014 Oct 2;15(4):599-613.

[7] Sheppard KW, Cheatham CL. Omega-6/omega-3 fatty acid intake of children and older adults in the US: dietary intake in comparison to current dietary recommendations and the Healthy Eating Index. Lipids in health and disease. 2018 Dec;17(1):1-2.

[8] Rosales FJ, Reznick JS, Zeisel SH. Understanding the role of nutrition in the brain and behavioral development of toddlers and preschool children: identifying and addressing methodological barriers. Nutritional neuroscience. 2009 Oct 1;12(5):190-202.

[9] Paciorek CJ, Stevens GA, Finucane MM, Ezzati M, Nutrition Impact Model Study Group. Children's height and weight in rural and urban populations in low-income and middle-income countries: a systematic analysis of population-representative data. The Lancet Global Health. 2013 Nov 1;1(5):e300-9.

[10] Adjepong M, Yakah W, Harris WS, Annan RA, Pontifex MB, Fenton JI. Whole blood n-3 fatty acids are associated with executive function in 2-6-year-old Northern Ghanaian children. The Journal of nutritional biochemistry. 2018 Jul 1;57:287-93.

[11] Osendarp SJ. The role of omega-3 fatty acids in child development. Oléagineux, Corps gras, Lipides. 2011 Nov 1;18(6):307-13.

[12] Liu J, Raine A. The effect of childhood malnutrition on externalizing behavior. Current opinion in pediatrics. 2006 Oct 1;18(5):565-70.

[13] Raine A. Annotation: The role of prefrontal deficits, low autonomic arousal, and early health factors in the development of antisocial and aggressive behavior in children. Journal of Child Psychology and Psychiatry. 2002 May;43(4):417-34.

[14] World Health Organization. Essential nutrition actions: improving maternal, newborn, infant and young child health and nutrition. 2013. https://apps.who.int/iris/bitstream/handle/10665/84409/9789241505550_eng.pdf

[15] Burdge GC, Sherman RC, Ali Z, Wootton SA, Jackson AA. Docosahexaenoic acid is selectively enriched in plasma phospholipids during pregnancy in Trinidadian women–results of a pilot study. Reproduction nutrition development. 2006 Jan 1;46(1):63-7.

[16] Gerster H. Can adults adequately convert a-linolenic acid (18: 3n-3) to eicosapentaenoic acid (20: 5n-3) and docosahexaenoic acid (22: 6n-3)?. International journal for vitamin and nutrition research. 1998;68(3):159-73.

[17] Burdge GC, Calder PC. Conversion of $\alpha $-linolenic acid to longer-chain polyunsaturated fatty acids in human adults. Reproduction Nutrition Development. 2005 Sep 1;45(5):581-97.

[18] Greenberg JA, Bell SJ, Van Ausdal W. Omega-3 fatty acid supplementation during pregnancy. Reviews in obstetrics and Gynecology. 2008;1(4):162.

[19] Shapira N, Sharon O. Multiple Fortified Egg for Comprehensive Nutritional and Health Support. InHandbook of Food Fortification and Health 2013 (pp. 3-20). Humana Press, New York, NY.

[20] National Institute of Health. Omega-3 fatty acids: Fact sheet for health professionals. 2020. https://ods.od.nih.gov/factsheets/Omega3FattyAcids-HealthProfessional/

[21] Winwood R. Disturbing EPA and DHA deficiency in small children in three different geographical locations in South Africa. 2016. https://www.nutri-facts.org/en_US/news/Disturbing-EPA-and-DHA-deficiency-in-small-children-in-three-different-geographical-locations-in-South-Africa.html

[22] Joint FA. Fats and fatty acids in human nutrition. Report of an expert consultation, 10-14 November 2008, Geneva. http://www.fao.org/3/a-i1953e.pdf

[23] Hamidu, J. A., Brown, C. A., Adomako, K. & Darko, J. O. Potential of Egusi and Neri seeds as sources of polyunsaturated fatty acids and amino acids for table eggs enrichment Ghana Journal Agricultural Science. (Unpublished).

[24] Prentice AM, Paul AA. Fat and energy needs of children in developing countries. The American journal of clinical nutrition. 2000 Nov 1;72(5):1253s-65s.

[25] Adjepong M, Pickens CA, Jain R, Harris WS, Annan RA, Fenton JI. Association of whole blood n-6 fatty acids with stunting in 2-to-6-year-old Northern Ghanaian children: A cross-sectional study. PloS one. 2018 Mar 1;13(3):e0193301.

[26] Adjepong M, Yakah W, Harris WS, Colecraft E, Marquis GS, Fenton JI. Association of whole blood fatty acids and growth in southern Ghanaian children 2-6 years of age. Nutrients. 2018 Aug;10(8):954.

[27] Table M. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. National Academy Press: Washington, DC, USA; 2005.

[28] Cave C, Hein N, Smith LM, Anderson-Berry A, Richter CK, Bisselou KS, Appiah AK, Kris-Etherton P, Skulas-Ray AC, Thompson M, Nordgren T*m. omega*-3 long-chain polyunsaturated fatty acids intake by ethnicity, income, and education level in the United States: NHANES 2003-2014. Nutrients. 2020 Jul;12(7):2045.

[29] van der Wurff IS, Meyer BJ, de Groot RH. Effect of omega-3 long chain polyunsaturated fatty acids (N-3 LCPUFA) supplementation on cognition

in children and adolescents: A systematic literature review with a focus on n-3 LCPUFA blood values and dose of DHA and EPA. Nutrients. 2020 Oct;12(10):3115.

[30] Harris WS, Von Schacky C. The Omega-3 Index: a new risk factor for death from coronary heart disease?. Preventive medicine. 2004 Jul 1;39(1):212-20.

[31] Williams CM, Burdge G. Long-chain n− 3 PUFA: plant v. marine sources. Proceedings of the Nutrition Society. 2006 Feb;65(1):42-50.

[32] Goyens PL, Spilker ME, Zock PL, Katan MB, Mensink RP. Conversion of α-linolenic acid in humans is influenced by the absolute amounts of α-linolenic acid and linoleic acid in the diet and not by their ratio. The American journal of clinical nutrition. 2006 Jun 1;84(1):44-53.

[33] Mathias RA, Fu W, Akey JM, Ainsworth HC, Torgerson DG, Ruczinski I, Sergeant S, Barnes KC, Chilton FH. Adaptive evolution of the FADS gene cluster within Africa. PloS one. 2012 Sep 19;7(9):e44926.

[34] Cherian G, Holsonbake TB, Goeger MP. Fatty acid composition and egg components of specialty eggs. Poultry Science. 2002 Jan 1;81(1):30-3.

[35] Sparks NH. The hen's egg-is its role in human nutrition changing?. World's Poultry Science Journal. 2006 Jun 1;62(2):308-15.

[36] Scheideler SE, Froning GW. The combined influence of dietary flaxseed variety, level, form, and storage conditions on egg production and composition among vitamin E-supplemented hens. Poultry Science. 1996 Oct 1;75(10):1221-6.

[37] Gillingham LG, Caston L, Leeson S, Hourtovenko K, Holub BJ. The effects of consuming docosahexaenoic acid (DHA)-enriched eggs on serum lipids and fatty acid compositions in statin-treated hypercholesterolemic male patients. Food research international. 2005 Dec 1;38(10):1117-23.

[38] World Health Organization. (2013). Essential nutrition actions: improving maternal, newborn, infant and young child health and nutrition. World Health Organization.

[39] Covington *M. omega*-3 fatty acids. American family physician. 2004 Jul 1;70(1):133-40.

[40] Brown CA. Paradigm shift in poultry feeding: the development of omega 3 enriched eggs. 2016. MPhil Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

[41] Garlick PJ. Protein requirements of infants and children. Protein and Energy Requirements in Infancy and Childhood. 2006;58:39-50.

[42] Agriculture, Forestry and Fisheries. A profile of the South African egg industry market value chain. 2010. https://www.daff.gov.za/docs/AMCP/EggMVCP2010-11.pdf.

[43] Simopoulos AP. The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. Experimental biology and medicine. 2008 Jun;233(6):674-88.