Childrens’ Nutritional Needs and Realities in an Emerging World

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Children in developing countries are faced with many nutritional challenges. On the one hand, food security is under threat [1] with inadequate energy intake and low dietary diversity [2]; on the other hand, children are often exposed to diets typical of a Western lifestyle, leading to obesity and its attendant complications. This double burden of malnutrition is increasingly recognised in developing countries, particularly those in sub-Saharan Africa [3, 4].

In truth, children in developing countries have to contend with multiple challenges: micronutrient intake is often inadequate [5], macronutrients such as high-quality protein sources are inadequate [6], and food is frequently contaminated. Attention has previously focused on the nutritional needs of the infant and young child. Recently, studies have highlighted the poor intake of school children and adolescents and the potential that interventions in this age group may have to improve growth and development. In this issue of Annals of Nutrition and Metabolism, we address some of these questions (trends in childhood stunting and adulthood obesity, vitamin D and calcium metabolism, dietary intake in schoolchildren and adolescents, and the role of mycotoxins) with an emphasis on Africa.

In this issue, Norris et al. systematically review trends in childhood stunting and adult obesity in sub-Saharan Africa, the only region in the world where adolescent and youth populations are still growing. A disconcerting finding of this review is that despite economic growth, the prevalence of childhood stunting has not significantly decreased. Increased wealth has often only resulted in increased inequality, with the poor not benefiting from economic growth. This contrasts to other countries that have successfully addressed the health effects of economic disparities. African countries need to address the root causes of undernutrition if economic growth is to benefit all sectors of their populations.

In keeping with findings elsewhere, the prevalence of obesity, particularly in females, is increasing, and associated diseases such as diabetes have increased. Results of the recently published South African National Health and Nutrition Examination Survey indicate that almost 40% of females are overweight and 20% are obese [9]. Not unexpectedly, diabetes now is also common; approximately 10% of the adults surveyed had diabetes, and in a similar percentage diabetes should be excluded.

Vitamin D and calcium are required for normal health and attention has focused on the importance of these nutrients during childhood to prevent bone disease in adults. Although much of the data have been derived from developed countries, there is an increasing realisation that the position in developing countries is potentially more serious as populations start to age.

Calcium intake in children in developing countries is often low due to poor dairy intake. In this situation, adequate vitamin D status is crucial to ensure optimal absorption of calcium. Infants and children in developing countries are dependent largely on sun exposure to meet their vitamin D requirements. Despite the fact that most of these countries lie in regions with ample sun exposure, vitamin D deficiency is common due to factors such as overcrowding, pollution, and cultural norms related to clothing.

Pettifor discusses the interaction between vitamin D and calcium status in children in developing countries, the potential effects on bone health, and evidence for supplementation. Interpretation of the available evidence is confounded by inconsistent guidelines for normal vitamin D status and appropriate measures of bone mineral
content. There appears to be no clear long-term benefit in providing calcium supplements, and there are disturbing data suggesting that supplementation may be detrimental in certain children.

Although most adolescents live in developing countries, few studies have addressed their dietary intake. Academic performance is influenced by their nutritional status, and early adolescence is the last window of opportunity to achieve optimal growth and physical development. During this period of rapid growth and development and increasing autonomy, unhealthy dietary habits often develop.

Studies from developed countries show that adolescents often follow unhealthy diets and that obesity is increasing in this age group. Unfortunately, data from developing countries are limited; it is difficult to interpret the little information that is available due to the numerous problems that are a feature of the nutritional assessment of adolescents, differences in methodologies used, and the inherent shortcomings of these methodologies. Despite these limitations, it is clear that a significant proportion of school children and adolescents have inadequate diets. Total energy and micronutrient intakes are often low. In particular, breakfast is of poor quality and may affect learners’ attention span. Some school feeding programmes have demonstrated encouraging results with improvement in school attendance and scholastic performance.

On the other hand, adolescents in developing countries will, when possible, consume energy-dense snacks and other Western-style foods which are often available in school canteens in preference to more traditional fare. Many commercial fast-food chains have realised the economic potential of the market launching outlets in disadvantaged areas in developing countries. Ochola and Masiibo review the methodological considerations that we should be aware of when interpreting available data and briefly outline what is known of dietary intake in schoolchildren and adolescents in developing countries.

Although the role of mycotoxins in childhood disease and malnutrition has long been suggested, their possible importance is often not appreciated by health professionals caring for children. They were previously implicated in the aetiology of esoteric conditions such as onyalai [7] and common nutritional diseases such as kwashiorkor [8]. In this issue, Lombard provides a review of recent studies on mycotoxin exposure in children. These low-molecular-weight metabolites cross the placental barrier, are excreted in breast milk, and are present in many complementary feeds. Infants are at increased risk of the deleterious effects of these toxins due to immature detoxification capacity.

High levels of exposure have been documented in a number of African and other tropical countries. This is due to consumption of products that are easily contaminated with fungi, particularly where storage techniques in rural areas are not appropriate. Exposure often shows a seasonal variation which may contribute to seasonal variations in the growth of young children. Mycotoxin exposure is associated with stunting and poor weight gain in children. A number of mechanisms may account for this effect: mucosal injury with increased permeability, decreased nutrient absorption, zinc deficiency, and increased systemic inflammation.

Although much of the data are preliminary, the implications for young children living in tropical countries could be far reaching. Nutritional support programmes will be ineffective if they do not also address contamination of food with mycotoxins and other potentially deleterious substances.

Etienne Nel

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Etienne Nel
Stunting has adverse long-term consequences for children’s immune function and survival, risk of nutrition-related chronic diseases, cognitive and behavioral development, and human capital.

Key insights
Stunting in under-5-year-old children still plagues Africa and has not decreased as rapidly as the concomitant increase in economic growth. The persistence of disease and socioeconomic inequality ensures that not all segments of the population, in particular the most vulnerable, benefit equally from economic growth. Further compounding the problem is the association between economic progress and obesity, especially amongst females. More and more African countries are now being afflicted with the double burden of malnutrition.

Current knowledge
There have been successes in reducing stunting in other low- or middle-income countries. For example, Brazil’s dramatic reduction of the national stunting prevalence from 37.1 to 7.1% over a 33-year period was largely attributed to economic advancement and policies that combated inequality. Similarly, Mexico’s conditional cash transfer and increased health-care access initiatives managed to decrease stunting by over 10%. Transitioning country environments that are unable to reduce early-life undernutrition but foster later-life overnutrition may accelerate the risk of metabolic diseases, such as type 2 diabetes.

Practical implications
A multisectorial response is needed to alleviate poverty, support gender equality, and improve access to health care and education. An important target population is females, where the goal is to improve maternal nutrition during pregnancy and infant nutrition through the promotion and support of breastfeeding. For children, growth monitoring and immunization campaigns can boost efforts to reduce child stunting. The complex challenge for many transitioning African countries will be to simultaneously address childhood stunting on one hand and the emergence of later adolescent/adult obesity on the other.

Recommended reading
Africa in Transition: Growth Trends in Children and Implications for Nutrition

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Key Messages
• Despite economic growth in Africa, stunting in under-5-year-old children is persistently high.
• Several African countries now face a double burden of malnutrition.
• To combat stunting in Africa, both policy and multisectoral interventions need to target the economically vulnerable.

Key Words
Africa · Stunting · Adult obesity · Nutrition · Economic development

Abstract
The aims of this paper were to: (1) review the literature and examine contemporary child growth in terms of stunting prevalence across Africa; (2) discuss child stunting within the context of economic growth and adult obesity, and (3) elucidate the implications for child nutrition. It is evident that stunting in under-5-year-old children still plagues Africa and has not decreased as expected in line with the concomitant improvement in economic development over the past decade.Persisting and possibly widening inequality ensures that not all segments of the population, in particular the most vulnerable, benefit equally from economic growth. Of concern is the association between the increasing economic progress across Africa and the rising adult obesity, especially amongst females. More and more African countries are now afflicted with a double burden of malnutrition. The implication for child nutrition is that African countries need not only apply a multisectoral approach to accelerate the reduction in stunting levels, but also to arrest and prevent obesity.

Introduction
Africa is undergoing significant demographic, economic, and nutrition transitions. By 2010, the population of Africa had hit the one billion mark, and in 2013, it was estimated that Africa had a population of 1.033 billion people [1]. Furthermore, sub-Saharan Africa is the only continent globally in which the adolescent and youth populations are increasing [2]. This ‘youth bulge’ is often quoted as the population change that could lead to a demographic dividend of accelerated economic growth as youth are drivers for economic advancement through participation in labour markets and also as consumers [3].
The United Nations Development Programme’s Regional Bureau for Africa reported that between 1990 and 2010 the gross domestic product (GDP) per capita of sub-Saharan African countries increased on average by 4%, which was greater than the global average for that period [4]. One would anticipate that increases in macroeconomic growth in sub-Saharan Africa would intensify food productivity and availability, infrastructure and public health services, employment, and living standards, all of which could have a positive impact on child nutrition.

Poor linear growth, or stunting (<2 SD length/height for age), is a suitable proxy for children’s general health and nutritional well-being. Stunting is a result of a complex combination of proximal and distal biological and environmental factors [see framework for actions to achieve optimum foetal and child nutrition and development; 5]. It has been demonstrated that stunting has adverse long-term consequences for children’s immune function and survival, risk of nutrition-related chronic diseases, cognitive and behavioural development, and human capital (educational attainment and economic productivity) [5, 6]. De Onis et al. [7] determined that over a period of 20 years (1990–2010), the prevalence of under-5-year-old stunting decreased by 15.1% (44.4–29.2%) in low- or middle-income countries (LMICs), but only diminished by 2% (40.3–38.2%) in Africa. In Asia, it decreased by an astounding 21% (48.6–27.6%), and in 2010, Latin America had the lowest stunting levels (13.5%) of LMICs. A stunting prevalence of approximately 6% persisted in high-income countries over that period. These trends represent a striking paradox in Africa in terms of economic progress and child linear growth faltering. This paradox would suggest that the economic growth in Africa has not been fully translated into: (1) improved access to good-quality food; (2) access to clean water and sanitation; (3) access to immunisation initiatives and maternal and child health services; (4) maternal education, and (5) poverty reduction [8].

While the stunting prevalence across African countries has not decreased as expected with concomitant increases in economic growth, adult obesity levels have risen. A study by Ziraba et al. [9] in 2009 reported a 35% increase in the prevalence of obesity between 1992 and 2005 in several African countries. The aims of this paper are to: (1) review the literature and examine contemporary child growth in terms of stunting prevalence across Africa; (2) set child stunting within the context of economic growth and adult obesity, and (3) discuss the implications for child nutrition.

**Methods**

**Information Sources and Search Strategy**

PRISMA guidelines for the reporting of systematic reviews informed the process [10]. Three authors (S.W., L.K.M., and R.S.M.) independently performed a literature search using three electronic databases (PubMed, Science Direct databases, and Cochrane Library) using National Library of Medicine Medical Subject Heading (MeSH) search terms to cover two key domains: (1) child (<5-year-old) stunting and (2) adult obesity. The words ‘prevalence’ and ‘Africa’ or ‘sub-Saharan Africa’ were used in combination with ‘stunting’, ‘stunted’, ‘undernutrition’, ‘height’, ‘length’, ‘malnutrition’, or adult ‘overweight’ or ‘obesity’. In addition, the search terms together with the names of each of the 54 African countries were used. Additional searches including ‘rural’ and ‘urban’ were conducted to report prevalence in both rural and urban contexts. We selected the limit function to restrict search results to published papers in English or French and human studies. The search was finalised in March 2014 and included all articles published between 2000 and 2013, but where limited data existed for an African country, the time period was expanded to include data before 2000.

Grey literature including the World Health Organisation (WHO) and United Nations Children’s Fund websites were searched for statistics and publications on child stunting and adult obesity in Africa. All African countries were individually searched for Demographic Health Surveillance data, and where data were available, the most recent data were included. African countries’ GDP per capita (an indicator of economic growth) and Gini index (an indicator of inequality) data were accessed from the World Bank (www.worldbank.org).

**Data Extraction**

Once duplicate references were removed, the titles and abstracts of the references were screened. Full-text articles were obtained and reviewed. Data were then extracted regarding country, setting (rural/urban), national or regional representation, age, gender, the year of the study, growth reference/standard used to determine stunting, and the prevalence of stunting or obesity. For the purpose of this paper, national studies were prioritised. Linear regressions were fitted to the data to explore associations.

**Results**

From the search on child stunting, 458 references were identified and reviewed, of which 131 references were included. The prevalence of stunting was determined for 50 of the 54 African countries and ranged from 10.1% in Tunisia to 50.7% in Ethiopia. It was noted that national assessments of stunting are not regular in all African coun-

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**Poor linear growth, or stunting, is a suitable proxy for children’s general health and nutritional well-being.**
tries, limiting the effective monitoring of nutritional indices over time at a country level. In countries that had multiple national assessments of stunting, the use of several growth references to define stunting, or different sampling methods to assess the prevalence of stunting in the population over time, complicated the interpretation. Considering the most recent assessments of the prevalence of stunting, 66% of African countries (33 of the 50 countries that had data) exhibit a high to very high prevalence of stunting (≥30%) according to the WHO classification for the assessment of the severity of malnutrition among children under 5 years of age (fig. 1). These figures would suggest that linear growth faltering in African children under 5 years of age is still a major public health concern for the majority of the countries in Africa. Within countries, the prevalence of stunting is generally higher in rural than urban areas. Finally, for the majority of African countries that assessed the prevalence of stunting by sex, male children had a higher prevalence than female children (online suppl. table A; for all online suppl. material, see www.karger.com/doi/10.1159/000365122). Economic development was measured by a change in GDP between 2000 and 2012 and tends to be inversely associated with child stunting. In some countries, such as Tunisia, stunting prevalence was relatively low despite only marginal economic growth, while in other countries, such as Nigeria, despite marked economic development, stunting prevalence was still high (fig. 2).

From the search on adult obesity, 1,038 references were identified and reviewed, and 153 were included. Clearly, obesity is increasing in Africa, particularly in women, and more specifically women residing in urban areas, with the highest obesity prevalence of 56% being reported in a regional study of urban Gambian women. The prevalence of female obesity ranges from as low as 1% in Ethiopia to 40% in Libya and Egypt (fig. 3). The highest prevalence of obesity appears to be in countries north of the Sahara desert as well as southern Africa, with the prevalence in most central African countries being <4%. South Africa, which has recently reported a female obesity prevalence of 39.2%, has the third highest obesity prevalence in Africa, with countries like the Seychelles, Tunisia, Algeria, and Sudan all reporting an obesity prevalence of >30%. Approximately one third of all African countries report a female obesity prevalence of >10%. In all countries in Africa, the obesity prevalence for females is significantly higher than that for males, with some countries reporting a 6- to 7-fold greater obesity prevalence in females compared to their male counterparts (online suppl. table B).

Economic development as measured by a change in GDP between 2000 and 2012 seems to be strongly associated with an increased adult female obesity prevalence (fig. 4). For several African countries, the prevalence of adult female obesity closely mirrors their respective economic growth, with South Africa standing out. Concomitantly, as African countries transition, adult obesity increas-
and child stunting decreases but still remains notably high, thus creating a scenario of a double burden of malnutrition in many African countries (fig. 5). Furthermore, with rising obesity, metabolic diseases such as type 2 diabetes become more prevalent (fig. 6; diabetes prevalence data from the International Diabetes Federation Diabetes Atlas).

**Discussion**

Floud et al. [11] documented that since the beginning of the 17th century and over a 300-year period, the average male in the UK had become taller by 10 cm and heavier, and that life expectancy had increased from 33 to 70 years. These changes over a long period of time were...
largely attributed to economic development [11]. This overall improvement in nutrition and health is reflected in the very low current levels of stunting in high-income countries, like the UK (<6% stunting in children under 5 years of age) [7]. From this review, stunting in under-5-year-old children in contemporary Africa is on average six times greater than that in the UK. However, there is marked variation in stunting prevalence across the African continent. Furthermore, stunting is not as low as one would have expected in line with the concurrent improvement in economic growth over the past period. Floud et al.’s [11] work suggests that the enduring hold of undernutrition across generations only unravels over a long time, and that a few decades of economic development in Africa may be too short a period.

Recently, Vollmer et al. [12] analysed data from 121 Demographic and Health Surveys from 36 LMICs, including several African countries, and unearthed weak evidence to support that economic development reduces undernutrition in early childhood. In a 7-country case study, the United Nations Development Programme found that the reduction in child undernutrition was not proportionate to economic growth as measured by GDP. Indeed, the fastest growing economies did not perform better in reducing child undernutrition, as inequality was still pervasive. Thus, the most vulnerable within the population did not benefit in the same way [4]. South Africa is an illustrative example of this. South Africa has had the second greatest increase in GDP over the past decade, but also has the second highest Gini index (measure of inequality) in Africa (online suppl. fig. 1) and a stunting prevalence (19.5%) that is almost triple that of Brazil. The ubiquitous inequality in South Africa has likely obstructed the benefit of the past economic advances. However, other factors such as HIV are also likely to have had an impact.

In addition, this review highlights the association between increasing economic progress across Africa and rising adult obesity, particularly amongst females. This increase in adult obesity is likely accelerating the non-communicable disease burden, such as diabetes (fig. 6). More and more African communities are now afflicted with a double burden of malnutrition. In South Africa, alongside a stubborn stunting prevalence in children, staggering adult female obesity prevalence (39.2%), and rising diabetes burden (10%), overweight and obesity are increasing in children and adolescents [13]. The recent South African National Health and Nutrition Examination Survey found that 25% of young children (2–4 years of age) were either overweight or obese [13].

In other LMICs, there have been successes in reducing stunting. For example, Brazil’s dramatic reduction in the national stunting prevalence from 37.1 to 7.1% over a 33-year period was largely attributed to economic advancement coupled with policies that combated inequality and were able to increase the socioeconomic status of poor families. The Brazilian example illustrates the positive impact that interventions which promote income redistribution and universal access to basic services can have on child undernutrition [14]. Similarly, Mexico’s conditional cash transfer initiative (Oportunidades), where families received cash in exchange for complying with ‘conditionalities’, such as nutrition supplementation and growth and health monitoring, resulted in a lower prevalence of stunting and a host of other physical and cognitive benefits [15].

Headey [8] argues that if economic growth can be turned into ‘nutrition-sensitive’ economic growth, then it can significantly reduce child undernutrition and improve linear growth. Vollmer et al. [12] suggest that targeted health and nutrition interventions will be more effective in improving child nutrition as they lessen the reliance of a ‘trickle-down approach’. These arguments would suggest that a multisectoral response is warranted: (1) macro-level economic growth coupled with sustained agricultural supply; (2) social sector development that addresses household poverty alleviation, education, and gender equality, and (3) community ‘first 1,000 days’ initiatives to improve maternal and child nutrition through the promotion of regular attendance of ante- and postnatal health services, breastfeeding support, child linear growth monitoring, and immunisation campaigns can boost efforts to reduce child stunting and undernutrition.

The complex challenge for many transitioning African countries will be to simultaneously address childhood stunting, on the one hand, and the emergence of later child/adult obesity, on the other.
choice and practice, and (3) enable more physical activity and less sedentary behaviour may combat obesity.

In conclusion, to address the gap in Africa to ensure that all children reach their potential to become healthy and productive adults may seem overwhelming, but the potential gains with success are considerable. More research and national monitoring of malnutrition including both under- and overnutrition is needed in Africa to assist in understanding growth trends and responses to multisectoral interventions and policy changes.

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References

Vitamin D deficiency and low dietary calcium intakes act synergistically in increasing the prevalence of rickets in communities where both problems are present.

Key insights
An important role of vitamin D is to modulate the body’s ability to adjust to changing calcium supply and demand. This is particularly important in developing countries, where calcium intakes are low. For dietary calcium, the consumption of dairy products was found to be a major source of this mineral. Although many children in developing countries do not meet the recommended daily intake of calcium, a large proportion of them are considered to have good bone status.

Current knowledge
Nutritional rickets is a global public health problem, affecting mainly infants and adolescents in developing countries. In some countries, vitamin D deficiency is the cause, resulting from social customs that limit sunlight exposure. In other countries where sunlight exposure is not a problem, low dietary calcium underlies the onset of rickets in older toddlers and children. The negative effects of calcium and vitamin D deficiency may have varying influences depending on genetic background and ethnic origin.

Practical implications
The factors that contribute to low vitamin D status in infants and children include overcrowding, atmospheric pollution, and clothing customs. The infant and adolescent age groups are at highest risk, particularly girls. Calcium homeostasis can effectively be adapted to low calcium intakes even with diets which are thought to impair intestinal calcium absorption. However, very low calcium intakes (below 200 mg/day) greatly increase the risk of rickets and osteomalacia. Calcium supplements should be used with caution, as they do not appear to improve growth and may have adverse effects on height, although there are benefits on bone mass.

Recommended reading
Calcium and Vitamin D Metabolism in Children in Developing Countries

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Key Messages
- In most developing countries, dietary calcium intakes of children and adolescents are approximately 1/3 to 1/2 of the recommended intakes for children living in developed countries, yet the majority of children adapt well to these lower intakes and appear to suffer no adverse effects.
- Nutritional rickets remains a public health problem among infants, young children, and adolescents in many developing countries, even in those lying within the tropical and subtropical regions of the world. Although vitamin D deficiency remains the commonest cause due to overcrowding, atmospheric pollution, and lack of sunlight exposure of lactating mothers and their infants, increasing evidence indicates that in some countries, children on very low calcium intakes may develop dietary calcium deficiency rickets.

Abstract
Low dietary calcium intakes and poor vitamin D status are common findings in children living in developing countries. Despite many of the countries lying within the tropics and sub tropics, overcrowding, atmospheric pollution, a lack of vitamin D-fortified foods, and social customs that limit skin exposure to sunlight are major factors in the development of vitamin D deficiency. Low dietary calcium intakes are typically observed as a consequence of a diet limited in dairy products and high in phytates and oxalates which reduce calcium bioavailability. Calcium intakes of many children are a third to a half of the recommended intakes for children living in developed countries, yet the consequences of these low intakes are poorly understood as there is limited research in this area. It appears that the body adapts very adequately to these low intakes through reducing renal calcium excretion and increasing fractional intestinal absorption. However, severe deficiencies of either calcium or vitamin D can result in nutritional rickets, and low dietary calcium intakes in association with vitamin D insufficiency act synergistically to exacerbate the development of rickets. Calcium supplementation in children from developing countries slightly increases bone mass, but the benefit is usually lost on withdrawal of the supplement. It is suggested that the major effect of calcium supplementation is on reducing the bone remodelling space rather than structurally increasing bone size or volumetric bone density. Limited evidence from one study raises concerns about the use of calcium supplements in children on habitually low calcium intakes as the previously supplemented group went through puberty earlier and had a final height several centimetres shorter than the controls.
Introduction
In the osteoporosis literature, considerable emphasis has been placed on the importance of ensuring that peak bone mass is optimised in early adulthood so as to reduce the prevalence of low bone mass and osteoporotic fractures in the postmenopausal period in women and in elderly men. Until recently, this concept has been considered to be of importance only for high-income countries, where the proportion of elderly in the population has been increasing progressively and the cost of managing osteoporosis and its complications is an ever increasing burden on the health system, which in the USA was estimated to be 17 billion USD in direct costs in 2006 [1]. However, attention is now being drawn to the likely dramatic escalation of osteoporosis prevalence in low- and middle-income countries, where lifestyle and demographic changes will result in the proportion of all fractures rising from 50 to 75% from 1990 to 2050 [2].

Attention is now being drawn to the likely dramatic escalation of osteoporosis prevalence in low- and middle-income countries, where lifestyle and demographic changes will result in the proportion of all fractures rising from 50 to 75% from 1990 to 2050.

Although genetics plays an important role in determining peak bone mass, environmental factors, such as nutrition [3] and physical exercise (especially in late childhood and early puberty) [4], are considered to be important modulators of an individual’s genetic potential. In countries where malnutrition is prevalent, it is clear that many factors, such as impaired growth, and nutrient deficiencies, such as protein and trace element deficiencies, also play important roles in determining bone mass and health in children [5]. Many researchers, however, believe that overall dietary calcium intake and vitamin D status are the two major nutritional factors influencing optimal bone development in childhood and adolescence [6]. In this review, I shall summarise the physiology and synergy between vitamin D and calcium, and discuss vitamin D status and dietary calcium intakes in developing countries and the effects of low vitamin D status and calcium intake on child health and development.

The Physiology of Vitamin D and Calcium

Vitamin D
Although vitamin D is considered to be a major player in bone development and homeostasis, it has other physiological roles as well. Over the past few decades, researchers have suggested that vitamin D may have other actions besides those associated with bone and mineral homeostasis. These non-classical actions of vitamin D include possible roles in immune function, autoimmune diseases, and allergy, certain cancers, such as breast, colon, and prostate, cardiovascular and metabolic diseases, and neurological disorders, such as multiple sclerosis [7]. Although these possible roles have created much excitement, a number of researchers and committees have cautioned that, although the results are of interest, empirical research to support these claims is limited [8, 9]. I shall thus not discuss these possible roles any further.

Clinical and animal studies have highlighted the central role that vitamin D plays in the physiology of mineral homeostasis by maintaining normocalcaemia through optimising intestinal calcium absorption, even at the expense of skeletal mineralisation [10]. In vitamin D-replete children and adolescents on adequate calcium intakes, approximately one third of the dietary calcium intake is absorbed, although the variation is large [11]. In vitamin D deficiency, calcium absorption has been reported to be reduced to 10–15% [12], but is not negated completely. Vitamin D-dependent intestinal calcium absorption is an important process when calcium intakes are low, as absorption is mainly transcellular and dependent on active transport involving vitamin D-dependent TRPV6 and calmodulin-D$_{9k}$ in intestinal mucosal cells [13]. Passive paracellular calcium transport plays a major role in calcium absorption when calcium intakes are high, and probably in early neonatal life as well. The mechanism for the increased intestinal calcium absorption that occurs during pregnancy appears to be independent of vitamin D, but possibly dependent on oestrogen [13].

Thus, vitamin D status is a key factor influencing the body’s ability to adjust to changing calcium supply and demand, as for example may occur at the time of weaning when dietary calcium intake may fall or during the adolescent growth spurt when calcium accretion rates into bone are maximal. This role of vitamin D is of particular importance in developing countries where calcium intakes are characteristically low and of reduced bioavailability (see later).
The Assessment of Vitamin D Status

The last 20 years have seen considerable discussion around the definitions of vitamin D sufficiency and deficiency. There is general agreement that serum 25-hydroxyvitamin D (25-OHD) concentrations are an appropriate reflection of both dietary intake and cutaneous synthesis of vitamin D, but there is still only limited consensus as to what should be considered an appropriate cutoff of 25-OHD to differentiate an adequate vitamin D status from an inadequate one. Much of the dissent centres round whether or not the cutoff should take into consideration the possible non-classical actions of vitamin D. In 2011, the Institute of Medicine of the National Academy of Sciences in the USA released its Committee’s report on the dietary reference intakes for vitamin D and calcium, in which vitamin D sufficiency was defined as a 25-OHD concentration of >50 nmol/l, while the risk of vitamin D deficiency was considered to increase when 25-OHD was <30 nmol/l [9, 14]. In the same year, the Endocrine Society issued its clinical guideline for the evaluation of vitamin D deficiency [15], in which it defined 25-OHD <50 nmol/l as deficient and ≥75 nmol/l as optimal. A number of specific paediatric guidelines have also been published. The European Society for Paediatric Gastroenterology, Hepatology and Nutrition has highlighted the difficulty in defining a cut-point for vitamin D deficiency but recommends 25-OHD >50 nmol/l as indicative of sufficiency and <25 nmol/l as indicative of severe deficiency [16]. The American Academy of Pediatrics has defined deficiency as 25-OHD ≤37.5 nmol/l and sufficiency as 50–250 nmol/l [17]. From a paediatric bone health perspective, it is frequently considered that 25-OHD of <25 or 30 nmol/l is necessary before disturbances in bone health are seen [18].

A number of studies have estimated the prevalence of vitamin D deficiency in different countries around the world using a variety of different cutoffs for 25-OHD to diagnose deficiency [6, 18–20]. Prentice’s [18] paper highlights the effect of using different 25-OHD cutoffs on the prevalence of vitamin D deficiency in the UK. Across adults’ and children’s age ranges, the prevalence varied between 20 and 50% if a cutoff of 50 nmol/l was used, while the prevalence was 5–20% if 25 nmol/l was used. Utilising 50 nmol/l as the cutoff globally, it has been estimated that over 1 billion people would be classified as being vitamin D deficient, and would result in the majority of countries having a large proportion of their populations being classified as such [20]. However, there is little information on vitamin D status from most developing countries. Arabi et al. [19], looking specifically at data from developing countries, were only able to find information on 23 of 144 such countries. Despite many of the developing countries lying within the tropical and subtropical zones and thus being exposed to UV radiation around the year, the authors concluded that hypovitaminosis D (varying cut-points were used, but the majority of studies used <37.5 or <25 nmol/l) was prevalent in most areas of the world, especially in the Middle East and North Africa, China and South Asia (India, Pakistan, and Bangladesh). There are, however, a number of caveats that must be highlighted, the most important of which being that the studies only represented a small proportion of all developing countries and, therefore, may not typify the picture in all such countries and that the paediatric age ranges were generally poorly covered. Very few studies have been conducted among children in Africa, but studies from the Gambia [18] and Nigeria [21] on the west coast and South Africa [22] have indicated that vitamin D deficiency is uncommon in ambulatory children and adolescents, but information on early infancy is limited. Studies from Ethiopia [23] and Sudan [24] suggest that infantile rickets due to vitamin D deficiency is not uncommon and is associated with malnutrition, limited sunlight exposure, and prolonged breastfeeding. Traditional indigenous ethnic groups within Tanzania were found to be vitamin D replete with 25-OHD concentrations well above 50 nmol/l [25]. In general, the factors responsible for a low vitamin D status among infants and children in developing countries reflect inadequate skin exposure to UV radiation as a consequence of overcrowding, atmospheric pollution, little opportunity to play out of doors, and clothing customs, ensuring extensive skin coverage.

If reports on vitamin D deficiency rickets/osteomalacia are used as a guide to assess the age groups at risk of vitamin D deficiency, then in most countries, it is the infant and adolescent age groups who are most at risk. In the adolescent age group in many developing countries, it is girls who are most prone to vitamin D deficiency due to cultural practices which see greater skin coverage by clothing and reduced outside activities by girls. Children in most developing countries are almost exclusively de-
dependent on the cutaneous synthesis of vitamin D rather than on dietary intake, as very few available foods (besides oily fish) in these regions naturally contain significant amounts of vitamin D or are vitamin D fortified. Breastfed infants in developing countries are also largely dependent on UV radiation to ensure their vitamin D status, as the vitamin D status of pregnant and lactating women is frequently poor resulting in low 25-OHD concentrations in the neonate and low vitamin D content in breast milk [26]. Studies have suggested that lactating mothers may need vitamin D supplements as high as 6,400 IU/day for sufficient vitamin D to cross in breast milk to ensure infant 25-OHD concentrations equivalent to those obtained if the infant was supplemented with 400 IU/day directly [27]. Supplements with doses as high as those given to the lactating mothers in the above study are not recommended until they have been shown to be safe in large clinical trials.

**Calcium**

In most populations, dietary calcium intakes are largely dependent on dairy product consumption. In 1990, the Food and Agriculture Organisation (FAO) estimated that the average per capita calcium intake in developed countries was 850 mg/day compared to 344 mg/day in developing countries. The major nutrient difference responsible for the markedly lower calcium intakes in developing countries was the proportion of calcium derived from animal (dairy) sources [28]. The FAO-estimated per capita consumption in developing countries is very similar to the average calcium intakes of children who have been assessed by food frequency questionnaires and 24-hour dietary assessments in a number of different countries (table 1). Thus, many children have intakes of 300–400 mg/day, which are mainly derived from vegetable sources, as dairy product consumption is limited once weaning occurs, except possibly in more affluent communities [37].

Recommended dietary calcium intakes vary between different countries, but using the recent recommendations from the Institute of Medicine of the National Academy of Sciences, USA, as a guideline, its recommended daily allowance (RDA) for children increased between the ages of 1 year and 18 years from 700 to 1,300 mg/day and its estimated average requirement increased from 500 to 1,100 mg/day [38]. Clearly, many children in developing countries do not meet these recommendations, yet the majority would be considered healthy, as far as bone status is concerned.

### Table 1. Calcium intakes in children in a number of developing countries around the world

<table>
<thead>
<tr>
<th>Country</th>
<th>Age, years</th>
<th>Calcium intake, mg/day</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya (rural)</td>
<td>7</td>
<td>316 ± 0.4</td>
<td>29</td>
</tr>
<tr>
<td>South Africa (rural)</td>
<td>3–5</td>
<td>282 ± 144</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>8–10</td>
<td>338 ± 170</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13–16</td>
<td>378 ± 279</td>
<td></td>
</tr>
<tr>
<td>Bangladesh (rural)</td>
<td>2–4</td>
<td>142 ± 67</td>
<td>31</td>
</tr>
<tr>
<td>India (urban)</td>
<td>2–4</td>
<td>172 ± 62</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>10–18</td>
<td>314 ± 194 (low SES)</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>713 ± 241 (high SES)</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>&lt;5</td>
<td>123 ± 130</td>
<td>34</td>
</tr>
<tr>
<td>China</td>
<td>10 ± 0.4</td>
<td>433 ± 170</td>
<td>35</td>
</tr>
<tr>
<td>Brazil</td>
<td>1–6</td>
<td>728–763</td>
<td>36</td>
</tr>
</tbody>
</table>

SES = Socioeconomic status. Calcium intakes are given as the mean, with or without the standard deviation. If a range is shown, it implies that there was a range of means for the age group quoted.

How Do Children Adapt to Low Calcium Content of Diets?

As mentioned earlier, calcium homeostasis is maintained mainly by controlling the gastrointestinal absorption of calcium. Typically, calcium absorption at recommended intakes is an active process, dependent on an adequate vitamin D status and intact renal and parathyroid function. Fractional calcium absorption is inversely proportional to calcium intake, but is also greater in African-American than in white American pre- and postmenarchal girls (39 vs. 30 and 44 vs. 25%, respectively, at intakes of approximately 900 mg/day) [39]. A few absorption studies have been conducted in children in developing countries, where calcium intakes are less than half those of children living in developed countries. In Nigeria, Thacher and Abrams [40] found a mean fractional absorption of 61% in children between 2 and 14 years of age with a mean calcium intake of 227 mg/day. This fractional absorption is very similar to that of 63.1% reported for Chinese children on low calcium intakes of 359 mg/day [41]. These values are thus approximately double those of children on calcium intakes close to the RDA. Children on low calcium intakes also reduce their renal excretion of calcium, but the obligatory loss of calcium from the gastrointestinal tract is similar in those on normal and low calcium intakes. It thus appears that children on habitually low dietary calcium intakes adapt very effectively to these lower intakes, probably through stimulation of renal CYP27B1 (1-α hydroxylase) and increased produc-
tion of 1,25-(OH)₂D. What is not known, however, is whether this is only achieved at higher circulating 25-OHD concentrations than are required by children on higher calcium intakes. Further, it is unclear at what level of calcium intake bone mass becomes negatively affected, and if it does, whether it is more likely to occur when bone accretion is maximal during the period of peak height velocity during puberty. Although calcium supplementation of diets has been shown to increase bone mass marginally in children, the effects are marginal and generally only maintained during supplementation [42]. This effective adaptation of calcium homeostasis to low calcium intakes is achieved on diets frequently high in phytates and oxalates which are thought to impair intestinal calcium absorption in humans [43].

**Nutritional Rickets in Developing Countries**

As discussed earlier, nutritional rickets is a major public health problem affecting mainly infants and adolescents in many developing countries, even among those living within tropical or subtropical regions. In a number of these countries, such as Algeria, Egypt, Turkey, and the Middle East, vitamin D deficiency has been clearly established as the cause, resulting from social customs which limit skin exposure to sunlight and UV radiation of both the mother and her breastfed infant, and of adolescent girls, in particular.

In other countries, such as India [44], Bangladesh, Nigeria, and South Africa, reports have highlighted the role that low dietary calcium intakes play in the pathogenesis of rickets in generally older toddlers and children, in whom sunlight exposure is not limited. In all four countries, calcium intakes of those with rickets have been estimated to be approximately 200 mg/day. Although serum 25-OHD concentrations in affected children are lower than those in control subjects, the mean values are generally above 30 nmol/l, which is higher than those found in typical vitamin D deficiency. Another characteristic biochemical feature is the marked elevation of 1,25-(OH)₂D concentrations prior to treatment (fig. 1). Concentrations are generally 1.5–2 times higher than those found in age-matched community controls [45]. In a randomised controlled trial from Nigeria, children with rickets suspected of being due to dietary calcium deficiency responded better to calcium alone or to calcium and vitamin D supplements than to vitamin D alone [46]. In India, the response of children with active rickets to calcium supplements has been mixed, suggesting that both vitamin D and calcium deficiency are causes of rickets on the subcontinent [44, 47].

**Bone Mass in Children Living in Developing Countries**

A question of considerable importance to children and adolescents living in developing countries who have habitually low dietary calcium intakes is: ‘Is there any evidence of deleterious consequences of these low calcium intakes on bone mass accrual during childhood and adolescence and therefore on peak bone mass attained in early adulthood?’ as poor bone growth and impaired peak bone mass might influence the incidence of fractures during childhood and of osteoporosis and fragility fractures in later life. As discussed in the previous section, there is now good evidence that very low calcium intakes of approximately 200 mg/day may be associated with impaired

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Calcium and Vitamin D in Children

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mineralisation and rickets, but is there evidence that children whose intakes are above these very low values but below the RDA have reduced bone mass?

The interpretation of bone mass measurements during childhood is difficult because of the close relationship that the measured bone mass variables of bone area, bone mineral density (BMD), and bone mineral content (BMC) have with body height, weight, and pubertal development [48]. Thus, during the assessment and interpretation of bone mass in children and adolescents, these variables need to be taken into consideration. Because of marked differences in growth rates and pubertal development in children living in developing communities compared to those in more affluent societies, reference data generated in developed countries need to be used and interpreted with caution when assessing bone mass of children and adolescents in developing communities. Numerous environmental and genetic factors play roles in determining bone mass in a growing child.

In South Africa, studies have consistently shown ethnic differences in bone mass between black and white children and pre- and postmenopausal women. Black children and women have greater bone mass at the femoral neck than their white peers, despite calcium intakes of the black participants being approximately half those of whites, nutrition in general being poorer in the black groups, and the black participants being shorter than their white peers [49, 50]. Bone mass at the lumbar spine and whole body was found to be similar in blacks and whites after adjusting for differences in body size. These results differ from those reported for African-American and non-black children in the USA, where African-American children have greater bone area and BMC at all measured sites (lumbar spine, hip, radius, and whole body) than non-black children [48]. In South Africa, despite the lower calcium intakes and the poorer growth of black children, they have a fracture incidence approximately half that of white children even though X-ray absorptiometry-measured bone mass is similar at most skeletal sites [51].

In the Gambia, calcium supplementation (1,000 mg/day for 5 days a week) of pre- or early-pubertal children, who had habitual calcium intakes of approximately 340 mg/day, resulted in a 4–5% greater increase in radial BMC than in controls over 12 months [52]. The authors concluded that this rise was a result of a reduction in bone remodelling space rather than an actual increase in bone size or a correction of the effects of dietary calcium deficiency. The calcium supplements had no effect on growth during the period of administration, but on follow-up, after stopping the supplementation, previously supplemented boys had advanced mid-adolescent height growth and an earlier peak height velocity. The net effect was an earlier cessation of growth in the previously supplemented boys, who at 23 years of age were 3 cm shorter than their non-supplemented peers [53]. No long-term effects on growth or pubertal development were noted in girls. Although these finding have not yet been confirmed in other studies, they do raise concern that altering habitual intakes through supplementation may have unintended adverse consequences.

Paediatric reference values for BMC and BMD have been published from a number of developing countries, including India [54] and China [55]. Total body BMC and BMD were found to be lower at most ages in Indian and Chinese children than in Caucasians from Europe, even after correcting for differences in height. The Indian participants had normal growth parameters (using Indian growth references) and had been carefully selected from private schools, thus excluding children from poorer communities who were more likely to be more undernourished, have poorer vitamin D status, and have lower dietary calcium intakes. A number of supplementation studies using both calcium and/or vitamin D have been conducted in children from India, where vitamin D deficiency is a frequent finding. Groups receiving calcium and vitamin D had greater increases in bone mass than those receiving vitamin D alone [33, 56]. In China, calcium supplementation in children, who had habitually low calcium intakes of 280 mg/day, resulted in an increase in appendicular bone mass [57] similar to that reported from supplementation studies of children on much higher calcium intakes. As has been reported from a number of other calcium supplementation studies, the bone mass advantage was lost within 18 months of stopping the supplement [58]. The calcium supplements had no effect on growth.

Conclusions

Following weaning, children living in the majority of developing countries have habitual dietary calcium intakes between one third and a half of the recommended intakes for children in the developed world. For the ma-
majority of these children, there is little evidence to suggest that their mineral balance or bone mass is adversely affected by these low intakes, provided their vitamin D status in not compromised as well. There is, however, evidence that children on very low calcium intakes of approximately 200 mg/day or less may develop rickets and osteomalacia, which responds to treatment with calcium supplements alone. Further research is required to elucidate the various factors predisposing these children to rickets. Calcium supplementation in children from developing countries does not appear to improve growth and may in fact have adverse effects on final height. Bone mass increases during calcium supplementation, but most studies have found that the benefit is lost following cessation of the supplement.

Poor vitamin D status remains a major public health problem among infants, young children, and adolescents in many developing countries despite adequate sunshine and UV radiation. Overcrowding, atmospheric pollution, the lack of vitamin D-fortified food, and social customs which reduce sunlight exposure are major factors responsible for the high prevalence. Vitamin D deficiency and low dietary calcium intakes act synergistically in increasing the prevalence of rickets in communities where both problems are present.

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References


Childhood and adolescence are critical stages offering a window of opportunity for interventions to inculcate healthy eating habits to mitigate the occurrence of diet-related chronic diseases in later life associated with poor eating habits in earlier life.

Dietary Intake of Schoolchildren and Adolescents in Developing Countries
by Sophie Ochola and Peninah Kinya Masibo

Key insights
In developing countries, the diets of school-age children and adolescents are very limited in diversity. The pattern is characterized by minimal intake of animal foods, fruits and vegetables and high consumption of calorie-rich processed foods. The problem is further exacerbated by the replacement of traditional diets with Western diets in developing countries. Consequently, many children have an inadequate energy intake and are deficient in micronutrients.

Current knowledge
Data on dietary intake are critical for guiding health and nutritional interventions for children and adolescents. The school age and adolescent years comprise a dynamic period of growth and development that forms the basis for health and productivity in later life. This review of the dietary intake of schoolchildren and adolescents (aged 6–19 years) aimed to characterize the dietary patterns and assess the adequacy of nutrient intake in order to identify the effects on public health and nutrition. The analysis was based on 50 studies performed in 42 countries, published from 2000 to 2014.

Practical implications
Public health policies in developing countries must address the problems of over- and undernutrition within the same populations. In school-age children and adolescents, the pattern of energy consumption is not well distributed. These individuals (particularly those from low socioeconomic backgrounds) often skip breakfast with negative consequences for school performance and health outcomes. Dietary interventions should therefore consider the provision of school meals for improved health and performance. The consumption of processed food items is a major contributing factor to overweight and obesity. This highlights the need for nutrition education across the entire community, including school management, children and parents.

Recommended reading
Dietary Intake of Schoolchildren and Adolescents in Developing Countries

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Key Words
Dietary intake · Schoolchildren · Adolescents · Developing countries · Nutrition transition

Abstract
School age and adolescence is a dynamic period of growth and development forming a strong foundation for good health and productive adult life. Appropriate dietary intake is critical for forming good eating habits and provides the much needed nutrients for growth, long-term health, cognition and educational achievements. A large proportion of the population globally is in the school age or adolescence, with more than three quarters of these groups living in developing countries. An up-to-date review and discussion of the dietary intake of schoolchildren and adolescents in developing countries is suitable to provide recent data on patterns of dietary intake, adequacy of nutrient intake and their implications for public health and nutrition issues of concern. This review is based on literature published from 2000 to 2014 on dietary intake of schoolchildren and adolescents aged 6–19 years. A total of 50 studies from 42 countries reporting on dietary intake of schoolchildren and adolescents were included. The dietary intake of schoolchildren and adolescents in developing countries is limited in diversity, main-

Key Messages

• Diets of schoolchildren and adolescents in developing countries are limited in diversity, with minimal consumption of animal foods and fruits and vegetables. Consequently, many children are deficient in micronutrients.

• There is insufficient energy intake, on the one hand, and consumption of high-calorie foods is increasingly becoming popular among schoolchildren and adolescents in urban areas, on the other hand.

• Schoolchildren and adolescents often skip breakfast with negative consequences for attainment of good health and educational objectives. Interventions for dietary improvements should consider providing school meals for improved health and performance of the children.

• The consumption of fast and high-energy food items is a major contributing factor to overweight and obesity creating the emerging public health concerns of the nutrition transition and the occurrence of non-communicable diseases. There is need for nutrition education for school management, children, adolescents, parents and the community at large to sensitise them on healthy eating habits.
Introduction

School-age children make up a considerable portion of the world’s population [1], and more than three quarters of these children live in developing counties. Similarly, 18% of the world’s population are adolescents, with the vast majority (88%) living in developing countries [2]. School-age children and adolescents have an increased need for nutrients [3]. This dynamic period of growth and development forms a foundation for good adult health as children go through physical, emotional and social changes [4]. The health, physical growth, development and educational performance of schoolchildren depend largely on good nutrition. Undernourished children are prone to poor health because of the synergism between malnutrition and infections [5]. Nutritional status influences cognitive development and academic performance [6], and many studies have demonstrated the positive effects of adequate dietary intake on cognitive function and school performance of schoolchildren [7–14].

Adolescence is a critical period in the life span, characterised by major physical, chemical and emotional changes. Optimal growth and development and the delay or prevention of non-communicable diseases can be achieved through nutritionally adequate diets and leading active lifestyles [15]. Adolescents are more autonomous in their food choices, which are largely influenced by peer pressure, and tend to disregard healthy eating messages [16, 17]. There is scant research available on dietary intake of adolescents in developing countries. Snacking, skipping meals and intake of junk foods are common features of the diet of adolescents in developed countries, where most of the studies have been conducted [18]. Some of these eating habits are increasingly being observed in developing countries [19–22].

The assessment of dietary and nutrient intake is one of the most widely used indirect methods of establishing nutritional status. Estimating the true dietary and nutrient intake is extremely difficult. The main limitations of the common methods of assessing dietary intake centre on the accuracy of the data obtained by such methods in estimating an individual’s usual dietary intake [23]. This article reviews studies on the challenges of dietary intake assessment including methods of assessment, availability of appropriate food composition tables and dietary reference standards that have been used to estimate adequacy of nutrient intake. A discussion of dietary diversity, meal patterns, adequacy of nutrient intake and their implications for health, growth and development of children and adolescents is included. Emphasis is placed on both the effects of under- and overconsumption of food to reflect the current nutrition transition being experienced in the developing countries with the resultant increasing levels of overweight and obesity in school-age children [8, 24–30] and adolescents [31–34]. Childhood and adolescence are critical stages offering a window of opportunity for interventions to inculcate healthy eating habits to mitigate the occurrence of diet-related chronic diseases in later life associated with poor eating habits in earlier life. A discussion of the dietary intake of schoolchildren and adolescents in developing countries is suitable to point out data that are available for the formulation of food-based dietary models and guidelines to establish healthy dietary habits in these critical population groups.

Methodology

A literature search was conducted in various online databases to identify articles and publications on dietary intake of school-age children and adolescents from Africa, East Asia, South Asia, Western Asia, Latin America and the Caribbean. This classification of developing countries is as provided by the United Nations [35]. The literature search was conducted using the following key terms: dietary intake assessment methods, diet, dietary pattern, diet variety, diet score, food intake, food choices, school-age children, schoolchildren, adolescents, nutrient adequacy, micronutrient intake (specific vitamins and minerals) and names of countries of interest. The search was carried out in several databases: PubMed, Access to Global Online Research in Agriculture (AGORA), Biomed Central, Cambridge Journals, Hinari, Oxford Journals, Wiley Online Library, ScienceDirect, Cochrane Database of Sys-
Fig. 1. Developing countries with reviewed data on dietary intake of schoolchildren and adolescents.

tematic Reviews (CDSR), Springer, Elsevier, Directory of Open Access Journals, World Bank (data.worldbank.org), Informa Healthcare, SciELO, Korean Medical Journal Information and Google Scholar. Information was also searched on specific international organisations’ websites including the World Health Organization (WHO), UNICEF, World Food Programme and the World Bank. Studies and articles for review were limited to materials published from 2000 to 2014.

Literature was included in the review if it was written in English or a translated version into English was available, and if study subjects were 6–19 years of age. If the study was an intervention providing dietary and nutrient supplements to subjects, baseline findings were considered for inclusion if dietary intake was measured and reported at baseline. Studies for inclusion were evaluated on the basis of reported outcomes such as differences between dietary intake within age categories, sex or those that compared different settings and circumstances such as rural and urban setups and socioeconomic status.

Studies were excluded if the study sample included less than 50 subjects, if the research was conducted in acute humanitarian emergency circumstances or if the participants were selected based on specific health conditions. A total of 150 research articles were identified in the initial search, 91 were included for the review and 59 were excluded based on the exclusion criteria. Out of the included articles, 32 are summarised in table 1 with details of study designs, methods of assessing dietary intake, main target population and key findings. Data on schoolchildren and adolescents are presented and discussed together because many studies combine findings for the two age groups and do not have a clear definition of schoolchildren and adolescents. Reviewed studies were from all regions of the developing world (fig. 1).

Results

Methodology Issues in Assessing Dietary Intake in Schoolchildren and Adolescents

Dietary assessment of schoolchildren is challenged by the fact that cognitive abilities for self-reporting, good memory and long attention span required to answer the questionnaire, provide information about the food as well
Table 1. Summary of the selected literature with data on dietary intake of school children and adolescents in developing countries

<table>
<thead>
<tr>
<th>No.</th>
<th>Author and Year</th>
<th>Study title</th>
<th>Study design</th>
<th>Participants and study setting</th>
<th>Dietary intake assessment method</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rauber et al. [56], 2014</td>
<td>Diet quality from pre-school to school age in Brazilian children: a 4-year follow-up in a randomised control study</td>
<td>Longitudinal study</td>
<td>Children aged 3–4 years (n = 345) and 7–8 years (n = 307)</td>
<td>Two 24-hour dietary recalls and a healthy eating index</td>
<td>93.5% of the children 3–4 years of age and 96% of the children 7–8 years of age had diets that were poor or needed improvement. Percent of children meeting the recommended healthy eating index for various foods for children aged 7–8 years in the group that had received dietary counselling: vegetables 0%, fruits 2.3%, meat and legumes 11.5%, milk 42.7%, total fat 61.1%, cholesterol 96.2% and dietary fat 43.5%</td>
</tr>
<tr>
<td>2</td>
<td>Shroff et al. [21], 2013</td>
<td>Adherence to a snacking dietary pattern and soda intake are related to the development of adiposity: a prospective study in school-age children</td>
<td>Longitudinal study</td>
<td>Children aged 5–12 years, Colombia (n = 961)</td>
<td>Food frequency questionnaire</td>
<td>Snacking pattern was associated with higher BMI gain, mean change in subscapular:triceps skinfold thickness ratio. Soda intake was positively and significantly associated with change in BMI and waist circumference</td>
</tr>
<tr>
<td>3</td>
<td>Turyashemererwa et al. [48], 2013</td>
<td>Dietary patterns, anthropometric status, prevalence and risk factors for anaemia among school children aged 5–11 years in Central Uganda</td>
<td>Cross-sectional study</td>
<td>Primary school-children aged 5–11 years, peri-urban area of Uganda (n = 122)</td>
<td>Food frequency questionnaire</td>
<td>Anaemia was associated with not eating fish and fewer meals (1–2 per day). One main dietary pattern was identified explaining approximately 20.4% of the variability of intake in the population</td>
</tr>
<tr>
<td>4</td>
<td>Mwaniki and Makokha [5], 2013</td>
<td>Nutrition status and associated factors among children in public primary schools in Dagoretti, Nairobi, Kenya</td>
<td>Descriptive cross-sectional design</td>
<td>Students aged 4–11 years, Kenya (n = 208)</td>
<td>24-Hour recall</td>
<td>Breakfast contributed 10% of the daily energy intake. Few children consumed foods from more than 4 food groups. Cereal-based grains contributed 18% of the total diet, vegetables contributed 12%, meat contributed 8.5% and fruits contributed only 3%. Mean energy intake was 1,890 kcal per day: breakfast contributed 10% of the daily energy intake, 44.5% was from lunch and 45.3% from supper.</td>
</tr>
<tr>
<td>5</td>
<td>Mehta et al. [54], 2013</td>
<td>Nutritional contribution of mid day meal to dietary intake of school children in Ludhiana District of Punjab</td>
<td>Cross-sectional survey</td>
<td>Schoolchildren aged 7–9 years, Punjab, India (n = 200)</td>
<td>Three consecutive days, 24-hour recall method</td>
<td>Kadhi chawal was the most liked meal (45%) followed by sabji roti and dhal chawal (35%), dhal roti (30%) and channa roti (29%). The least preferred meal was sweet rice (26%). Inadequate nutrient intake: the energy and protein was below the recommended norms of 450 kcal and 12 g protein. The midday meal was found to be a substitute rather than a supplement for the home meal. The percent contribution of energy, protein and fat by the midday meal to the actual nutrient intake of children was 28.2, 51.7 and 27.5%, respectively. The percent contribution of other nutrients was 22.7% for β-carotene, 28.3% for thiamine, 25.3% for riboflavin, 28.7% for niacin, 23.6% for folacin, 15.2% for vitamin C, 25.7% for iron and 27.7% for calcium.</td>
</tr>
<tr>
<td>No.</td>
<td>Author et al.</td>
<td>Study title</td>
<td>Study design</td>
<td>Participants and study setting</td>
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<td>Main findings</td>
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<td>6</td>
<td>Doku et al. [64], 2013</td>
<td>Socio-economic differences in adolescents’ breakfast eating, fruit and vegetable consumption and physical activity in Ghana</td>
<td>Cross-sectional survey</td>
<td>Adolescents aged 12–18 years, Ghana (n = 1,195)</td>
<td>Food habit questionnaire</td>
<td>31% of adolescents took breakfast at less than 4 days/week, over half (56%) and 48%, respectively, rarely ate fruits and vegetables. Younger adolescents (12–15 years old) consumed fruits and vegetables frequently compared with older ones (16–18 years old). Boys were more likely to participate in physical activity than girls. Eating breakfast was more likely for adolescents from more affluent backgrounds than for those from less affluent ones. Reasons for not eating breakfast were: lack of food at home (50%), not enough time for breakfast (24%), cannot eat early in the morning (19%). Maternal educational attainment increased the probability of frequent fruit and vegetable intake. High school performance was associated with frequent fruit intake, whereas high or medium school performance increased the likelihood of vegetable intake compared with low school performance.</td>
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<tr>
<td>7</td>
<td>Barugahara et al. [42], 2013</td>
<td>Prevalence and risk factors of nutritional anaemia among female school children in Masindi district, western Uganda</td>
<td>Cross-sectional study</td>
<td>Adolescent girls aged 11–14 years, Uganda (n = 109)</td>
<td>24-Hour dietary recalls</td>
<td>There was a high intake of plant-based diets. There was excess intake of fibre. There was inadequate intake of iron, protein, folate, riboflavin, energy and vitamin A. Percent of adolescent girls with macronutrient intake below WHO DRI: protein 50%, protein 73% energy and 17% dietary fibre. Percent of school girls with intake of macronutrients above WHO DRI: 59% protein, 36% energy and 92% fibre. Percent of adolescent girls with micronutrient intake below WHO DRI: iron 55%, folate 79%, riboflavin 55%, vitamin C 20% and vitamin A 48%. Percent of adolescent girls with micronutrient intake above WHO DRI: iron 54%, folate 30%, riboflavin 54%, vitamin C 89% and vitamin A 61%.</td>
</tr>
<tr>
<td>8</td>
<td>Akhter et al. [37], 2013</td>
<td>Calcium and vitamin D related knowledge in 16–18 years old adolescents: does living in urban or rural areas matter?</td>
<td>Cross-sectional survey</td>
<td>Children aged 6–18 years from urban and rural areas, Bangladesh (n = 2,992)</td>
<td>Food frequency questionnaire</td>
<td>Lack of knowledge and awareness of calcium and vitamin D. Rural children were less familiar with vitamin D and osteoporosis, had higher diet milk consumption, engaged more in outdoor activities and had more exposure to sunlight.</td>
</tr>
<tr>
<td>9</td>
<td>Elhisadi [61], 2013</td>
<td>Food and nutrients intake among Libyan school children</td>
<td>Cross-sectional survey</td>
<td>Schoolchildren aged 6–9 years, boys and girls, Ghana (n = 550)</td>
<td>24-Hour dietary recall, food frequency questionnaire</td>
<td>The average daily intake of total protein was 226% (±25.4 SD). There was a higher intake of protein among boys than girls. Students overall consumed at least the RDA for all vitamins with the exception of vitamin B6 and carotene, which were nearly 1.5 times the recommendation. Energy intake expressed as a percentage of RDA of all children was 76% of RDA (±5.8). The schoolchildren in this study, of both sexes, reported an average daily vitamin B6 and carotene intake of 14% (±9.6) and 129% (±52.2), respectively. The average intake of total fat in percent of RDA was 91% (±9). The average daily fibre intake was 10.0 g (±7.9).</td>
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<tr>
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<td>10</td>
<td>Masibo [40], 2013</td>
<td>Effects of Initial Nutritional Status on the Responses to a School Feeding Programme among School Children Aged 6–13 years in the Millennium Villages Project, Siaya, Kenya</td>
<td>Longitudinal study</td>
<td>Schoolchildren aged 6–13 years, Kenya (n = 220)</td>
<td>Food frequency questionnaire</td>
<td>Energy intake was below the estimated energy requirement for 66% of the children&lt;br&gt;Low fat intake&lt;br&gt;Inadequate intake of vitamin A, calcium, zinc and selenium based on EAR&lt;br&gt;Protein and vitamin C intake was above the RDA and EAR, respectively</td>
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<td>11</td>
<td>Acham et al. [91], 2012</td>
<td>Breakfast, midday meals and academic achievement in rural primary schools in Uganda: implications for education and school health policy</td>
<td>Cross-sectional survey</td>
<td>Schoolchildren in Kumi district, eastern Uganda (n = 645)</td>
<td>Meal patterns – quantitative questionnaire</td>
<td>School achievement was significantly associated with consumption of breakfast and a midday meal, particularly for boys</td>
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<td>12</td>
<td>Kawade [52], 2012</td>
<td>Zinc status and its association with the health of adolescents: a review of studies in India</td>
<td>Intervention, provision of zinc-rich dietary supplements and ayurvedic jasad zinc tablet</td>
<td>Girls aged 10–16 years from two secondary schools, India (n = 630)</td>
<td>24-Hour recall method on 3 random days including Sunday</td>
<td>The prevalence of micronutrient deficiencies was high in these girls&lt;br&gt;Poor cognitive performance was seen in half of the girls, and salt taste perception was affected in 45%&lt;br&gt;Adolescent micronutrient quality index was correlated with nutrient intakes and blood micronutrient levels&lt;br&gt;Results of the intervention trial indicated that supplementation of zinc-rich recipes vis-à-vis ayurvedic jasad zinc tablets had the potential to improve plasma zinc status, cognitive performance and taste acuity in adolescent girls</td>
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<tr>
<td>13</td>
<td>Hinnig and Bergamaschi [57], 2012</td>
<td>Food items in the food intake of children aged seven to ten years</td>
<td>Longitudinal study</td>
<td>Schoolchildren aged 7–10 years, Brazil (n = 115)</td>
<td>Three-day food diaries</td>
<td>Rice beans and lentils contributed significantly to the total intake of energy and carbohydrates&lt;br&gt;Milk significantly contributed to the total intake of lipids, protein and energy&lt;br&gt;Carbohydrates and energy intake from sugar-sweetened beverages (sodas and processed juices) were important contributors to the total diet intake of the children</td>
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<td>14</td>
<td>Semproli et al. [79], 2011</td>
<td>Nutrient intake in 5–17-year-old African boys and girls in a rural district of Kenya</td>
<td>Cross-sectional study</td>
<td>Schoolchildren and adolescents aged 5–17 years, Kenya (n = 1,442)</td>
<td>24-Hour dietary recall</td>
<td>The diet was deficient in sodium, calcium and potassium&lt;br&gt;Nutrient adequacy ratios were correlated to anthropometric values, particularly in males&lt;br&gt;There were no correlations between anthropometric characteristics and sodium or vitamin C (in males and females) and vitamin A or potassium (in females)</td>
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<td>15</td>
<td>Gharib and Rasheed [49], 2011</td>
<td>Energy and macronutrient intake and dietary pattern among school children in Bahrain: a cross-sectional study</td>
<td>Cross-sectional descriptive study</td>
<td>Schoolboys and -girls aged 6–18 years, Bahrain (n = 2,594)</td>
<td>24-Hour dietary recall</td>
<td>Average energy intake was close to the estimated average requirements. Protein intake substantially exceeded the reference nutrient intake values as did daily sugar consumption. Dietary fibre intake was below the dietary reference values. Energy percent limits for total fat, saturated fat and cholesterol in 36–50% of the students. The polyunsaturated:saturated fat ratio remained at an unacceptable level of 0.6 for girls and boys. 50% daily consumption of soda drinks. High consumption of sweets, especially among girls (64.2 compared to 47.3% for boys). 50% consumed milk. One fourth were taking fruits and vegetables.</td>
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<tr>
<td>16</td>
<td>Abrahams et al. [7], 2011</td>
<td>What’s in the lunchbox? Dietary behaviour of learners from disadvantaged schools in the Western Cape, South Africa</td>
<td>Cross-sectional survey</td>
<td>Grade-4 learners aged 10–12 years, South Africa (n = 717)</td>
<td>24-Hour dietary recall and dietary diversity score</td>
<td>69% of learners carried a lunchbox to school and 49% had consumed at least one item purchased from the school food shop/vendor. Most lunchboxes contained white bread with processed meat, whereas the most frequent food shop/vendor purchase comprised chips/crisps. Children who carried a lunchbox to school were significantly associated with a lower BMI, were younger, had a higher standard of living, higher dietary diversity scores, consumed more meals per day, had greater self-efficacy and came from predominantly urban schools. Eating food from the vendors and shops was associated with a lower standard of living score and higher dietary diversity and meal scores.</td>
</tr>
<tr>
<td>17</td>
<td>Onimawo et al. [63], 2010</td>
<td>Assessment of anaemia and iron status of school age children (aged 7–12 years) in rural communities of Abia State, Nigeria</td>
<td>Cross-sectional study</td>
<td>Schoolchildren, 120 males and 129 females, Nigeria (n = 249)</td>
<td>24-Hour dietary recall, food frequency questionnaire and weighed inventory technique</td>
<td>Prevalence of anaemia was 82.6%, while iron deficiency was 77.8%. The average daily iron intake was 30% below the RDA. The main foods consumed by these rural children were rice, beans and cassava processed into gari or foofoot; these foods contain non-heme iron as well as several iron inhibitors like tannins, polyphenols and phytates.</td>
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<tr>
<td>18</td>
<td>Venter and Winterbach [22], 2010</td>
<td>Dietary fat knowledge and intake of mid-adolescents attending public schools in the Bellville/Durbanville area of the city of Cape Town</td>
<td>Cross-sectional descriptive survey</td>
<td>Adolescents aged 17 years attending public schools, South Africa (n = 168)</td>
<td>Qualitative screening questionnaire</td>
<td>The learners had relative knowledge of dietary fat intake. Adolescents’ diets were classified as typically Western, high in fat. Dietary fat knowledge was positively associated with their fat intake.</td>
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<tr>
<td>19</td>
<td>Nago et al. [55], 2010</td>
<td>Food, energy and macronutrient contributions of out-of-home foods in school-going adolescents in Cotonou, Benin</td>
<td>Cross-sectional study</td>
<td>Adolescents aged 13–19 years, Benin (n = 656)</td>
<td>24-Hour dietary recalls on 2 non-consecutive school days</td>
<td>Out-of-home prepared foods contributed more than 40% of the daily energy, fat, protein, carbohydrate and fibre intakes and of the daily weight of food in the adolescents. Out-of-home foods regularly taken at breakfast and afternoon snacks providing more than three-quarters of the daily energy intake. Low consumers of out-of-home foods ate more fruit and vegetables and cereal grain products than high consumers. High consumers of out-of-home foods took more sweets and ate energy-dense foods.</td>
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<td>20</td>
<td>Collison et al. [38], 2010</td>
<td>Sugar-sweetened carbonated beverage consumption correlates with BMI, waist circumference, and poor dietary choices in school children</td>
<td>Cross-sectional study</td>
<td>Adolescents aged 10–19 years, Saudi Arabia (n = 9,433)</td>
<td>Seven-day food frequency questionnaire</td>
<td>The overall prevalence of overweight and obesity was 12.2 and 27.0%, respectively, with boys having higher obesity rates than girls (p ≤ 0.001). Waist circumference and BMI was positively correlated with sugar-sweetened carbonated beverage intake in boys only. Sugar-sweetened carbonated beverage intake was positively associated with poor dietary choices in both males and females. Fast-food meal intake, savory snacks, i.e., desserts and total sugar consumption correlated with sugar-sweetened carbonated beverage intake in both boys ($r = 0.39, 0.13, 0.10$ and $0.52$, respectively; $p &lt; 0.001$) and girls ($r = 0.45, 0.23, 0.16$ and $0.55$, respectively; $p &lt; 0.001$). Older children reported eating significantly less fruit and vegetables than younger children, and less eggs, fish and cereals.</td>
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<tr>
<td>21</td>
<td>Bishwalata et al. [66], 2010</td>
<td>Overweight and obesity among schoolchildren in Manipur, India</td>
<td>Cross-sectional study</td>
<td>Schoolchildren, India (n = 3,356)</td>
<td>Qualitative dietary habits/patterns</td>
<td>Watching television for &gt;2 h a day, higher family income, not eating other types of vegetables in the past week was associated with obesity.</td>
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<td>22</td>
<td>Hong et al. [44], 2010</td>
<td>Factors associated with overweight/obesity in Ho Chi Minh city</td>
<td>Cross-sectional study</td>
<td>Students aged 11–16 years, China (n = 678)</td>
<td>Food frequency questionnaire</td>
<td>Determinants of overweight and obesity were: sex (higher in males), age (higher in younger children), schools located in wealthy districts, higher family economic status, higher parental education, overweight or obese parents, more time spent watching TV, frequent consumption of soft drinks and more time studying after class. The odds of overweight and obesity were lower with physical activity, availability of fruits at home, frequent consumption of fruit and vegetables.</td>
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<tr>
<td>23</td>
<td>Flores et al. [43], 2009</td>
<td>Energy and nutrient intake among Mexican school-aged children, Mexican National Health and Nutrition Survey 2006</td>
<td>Cross-sectional National Health and Nutrition Survey</td>
<td>Children aged 5–11 years, Mexico (n = 8,716)</td>
<td>Food frequency questionnaires</td>
<td>Median energy intake was 1,501 kcal/day (percent adequacy: 88.0). Children with the lowest socioeconomic status, indigenous Mexicans and those from rural areas showed the highest inadequacies for vitamin A, folate, zinc and calcium. Overweight children and those with the highest socioeconomic status had a higher risk of excessive intakes.</td>
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<td>24</td>
<td>Francis et al. [19], 2009</td>
<td>Fast-food and sweetened beverage consumption: association with overweight and high waist circumference in adolescents</td>
<td>Cross-sectional survey</td>
<td>Adolescents aged 15–19 years, Jamaica (n = 1,317)</td>
<td>Food frequency questionnaire</td>
<td>High waist circumference was associated with the absence of fruit consumption. Overweight was associated with high sweetened beverage consumption.</td>
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<td>25</td>
<td>Mitchikpe et al. [59], 2009</td>
<td>Seasonal variation in food pattern but not in energy and nutrient intakes of rural Beninese school-aged children</td>
<td>Longitudinal study</td>
<td>Children aged 6–8 years, Benin (n = 80)</td>
<td>Observed weighed records</td>
<td>Food pattern showed seasonal variations. Cereals, roots and tubers were the main staple foods. Contributions of animal products to the diet were very small. There were no differences in food patterns based on sex or/and if or not children were attending school. Median daily energy intakes were not different between seasons. Fat and vitamin C intake showed seasonal differences. Energy and nutrient intakes were different for boys and girls.</td>
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<td>26</td>
<td>Gewa et al. [51], 2014</td>
<td>Determining minimum food intake amounts for diet diversity scores to maximize associations with nutrient adequacy: an analysis of schoolchildren’s diets in rural Kenya</td>
<td>Cross-sectional survey</td>
<td>Schoolchildren, mean age 7 years, Kenya (n = 529)</td>
<td>Three non-consecutive 24-hour recalls</td>
<td>Only DDS based on a 15-gram minimum and DDS based on nutrient content were significantly associated with mean probability of adequacy after adjusting for energy intake</td>
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<td>27</td>
<td>Kim and Lee [50], 2008</td>
<td>Relationships between the nutrient intake status, dietary habits, academic stress and academic achievement in the elementary school children in Bucheon-si</td>
<td>Cross-sectional study</td>
<td>Fifth-graders in Bucheon-si, Gyeonggido, South Korea (n = 224)</td>
<td>24-Hour dietary recall</td>
<td>The overall nutrient intake and dietary habits were fairly good. Calcium and folate intake was less than 75% DRIs. Dietary habits of boys were inferior. There was a relationship between higher energy, protein, phosphorus, potassium, zinc, polyunsaturated fatty acids and n-6 fatty acid intakes. The overall academic performance was higher for those eating out less frequently. Children with higher comprehensive dietary habit scores had a better academic performance.</td>
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<tr>
<td>28</td>
<td>Li et al. [62], 2008</td>
<td>Factors associated with adolescents overweight and obesity at community, school and household levels in Xi’an City, China: results of hierarchical analysis</td>
<td>Cross-sectional nutritional study</td>
<td>Adolescents aged 11–17 years, China (n = 180)</td>
<td>24-Hour dietary recall, food frequency questionnaire</td>
<td>Factors associated with overweight and obesity: higher energy intake, living in urban areas, low physical activity, high household wealth, parental restrictions on purchasing snacks, parents being overweight and obese, having soft drinks more than four times per week, availability of home video games and not fussy about foods. Eating sweets was negatively associated with overweight and obesity. Boys had higher levels of overweight and obesity.</td>
</tr>
<tr>
<td>29</td>
<td>Krittaphol et al. [60], 2006</td>
<td>Primary school children from northeast Thailand are not at risk of selenium deficiency</td>
<td>Cross-sectional study</td>
<td>Rural schoolchildren aged 6–13 years, Thailand (n = 515)</td>
<td>One-day weighed diet records</td>
<td>Low, median intakes of energy, calcium, iron, zinc, vitamin A, B2, B2, C, niacin and dietary fibre. Adequate protein intake. Low dietary quality and low median energy intake was higher among stunted children compared to non-stunted children. No selenium deficiency.</td>
</tr>
<tr>
<td>30</td>
<td>Mai et al. [13], 2003</td>
<td>Micronutrient status of primary school girls in rural and urban areas of south Vietnam</td>
<td>Cross-sectional study</td>
<td>Girls aged 7–9 years, Vietnam (n = 284)</td>
<td>24-Hour dietary recall</td>
<td>The dietary micronutrient pattern of the rural group showed deficiency of iron, calcium, phosphorus, potassium, magnesium, β-carotene, vitamin A and vitamin C. In contrast, adequate consumption of these elements, except low β-carotene, was observed in the urban group.</td>
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<td>31</td>
<td>Ahmed et al. [41], 2006</td>
<td>Anaemia and vitamin A status among adolescent schoolboys in Dhaka City, Bangladesh</td>
<td>Cross-sectional study</td>
<td>Boys aged 11–16 years from 10 schools, Dhaka City (n = 381)</td>
<td>Food frequency questionnaire</td>
<td>Poor dietary habits. Age, BMI, parents’ occupation, serum vitamin A level and frequency of intakes of meat and fruit were significantly independently related to haemoglobin level.</td>
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BMI = Body mass index; DRI = dietary reference intake; RDA = recommended dietary allowance; EAR = estimated average requirement; TV = television; DDS = dietary diversity score.
as the time concept required for a comprehensive dietary intake review may not be fully developed in the school-age child [36]. While parents provide reliable recalls of food intake for children under the age of 8 years in the home setting, they may not be fully informed about the food consumed away from home. Dietary recall in adolescents is affected by lack of motivation to respond to dietary intake questionnaires, and body image may affect the willingness to report [36]. Assessment of dietary intake of adolescents is influenced by underreporting and misreporting, which is common among overweight and obese adolescents given that dietary intake is a major concern for them [7, 37–40].

There is a lack of population-specific dietary assessment tools in many developing countries. The duration of recall time, collection techniques and quantification of food intake data were observed to differ to a large extent across different studies. Food frequency questionnaires are the most commonly used method of assessing dietary intake in schoolchildren and adolescents in developing countries [19–21, 37–48]. The use of single 24-hour recalls was also relatively common [5, 7, 13, 42, 49, 50], while some studies used repeated 24-hour recalls [51–56]. Less commonly applied methods were 3-day food diaries [57], 7-day food diaries [58], observed weighed records [59] and 1-day weighed diet [60], while yet others used a combination of one or two methods [61–63]. To a lesser extent, qualitative methodologies were applied especially for an adolescent population. This method of dietary assessment was more frequently applied in adolescents [22, 64, 65] than in schoolchildren [66].

Methodological differences also occur with regard to the person interviewed to provide information on dietary intake for schoolchildren. In some studies, either the child [67–69] or the parents/caregivers were interviewed [13, 40, 45, 46, 70], while in others, both the parent and child were involved in answering the dietary intake questionnaires [13, 61, 69, 71]. There were differences in the administration of questionnaires; some parent-child pairs were interviewed at school [72], while in others, the questionnaire was self-administered [61].

It is noted that studies made efforts to increase the reliability of dietary recalls using food models, photographs or pictures [13, 42, 46, 68, 71, 73]. Determination of portion sizes is diverse in the studies reviewed. Household measures are mainly used to estimate portion sizes [46]. Methods of analysing diet quality also differed between the studies. For example, principle component analysis was used in Columbia [21] and in Kenya [51], while a healthy eating index was developed for diet quality analysis in Brazil [71, 73]. The comparability of dietary intake data is further affected by seasonality. Some studies are designed to measure seasonal variability in food intake, while the majority do not take this into consideration [45]. Although some researchers have used validated dietary intake assessment tools for schoolchildren [10, 19, 74–77], a number of others did not report the use of such tools.

### Food Composition Databases

A reliable food composition database that provides information on the nutrient composition of various foods and their bioavailability is necessary to assess dietary quality and estimate nutrient intake. There are various types of food composition databases used for estimating the nutrient intake in developing countries depending on the availability of country-specific food composition databases. The variability of diets and composite meals across various regions, countries and in-country differences makes it difficult to find uniformity in the use of common food composition tables. This limits comparability of nutrient intake between countries and regions within one country. The general strategy observed in the reviewed literature was the adoption of global food composition databases with modifications to fit in specific foods not available in the global datasets. In a few of the countries, there are county-specific food composition databases, for example in India [54], Benin [59], South Africa [78] and Brazil [73]. Integrated use of local and international food composition databases was reported in Brazil [21, 53], Kenya [40, 46, 79], Thailand [10], Malawi [72], Libya [61], Bahrain [49] and Vietnam [13].

### Estimating Nutrient Adequacy

The most commonly used methods of estimating nutrient adequacy in schoolchildren include the use of recommended daily allowances (RDAs) [13, 54, 58, 61, 71, 80] and various dietary reference intakes (DRIs) [45, 49–
In adolescents, the reference standards used to define adequacy of nutrient intake include the DRIs [81], RDAs [82] and reference nutrition intakes [59, 65]. In addition to the use of different dietary reference standards, reporting of nutrient adequacy was different in the various studies. Some studies reported the percent of subjects with adequate or inadequate intake [83–86], while others reported the mean or median nutrient intake or average intake [87–90]. These differences in reporting adequacy of nutrient intake limit comparability across various studies.

**Dietary Diversity**

School-age children in developing countries are mainly consuming plant-based diets which are predominantly from cereals, roots and tubers with limited animal source foods [41, 42, 45–47, 51, 56, 59, 65, 83, 84]. This dietary pattern is especially common in rural communities. In some studies, the intake of milk and dairy products was observed in 50% of schoolchildren [49], while in others, milk was completely missing from the diet [41, 51]. Cereals and snacks were the most important sources of energy, contributing 27 and 18%, respectively, of the daily energy intake among schoolchildren of 6–12 years in Taiwan [84]. Over 7 days, 78% of adolescent boys did not consume liver, 33% did not consume milk, 38% did not consume small fish, 21% did not consume large fish and 23% did not consume dark green leafy vegetables in Bangladesh [41]. Animal products contributed only 7% of daily protein intake among Benin school-age children, while cereals provided 34 and 50% of the daily iron intake during post- and pre-harvest seasons, respectively [59]. The inadequate intake of dark green leafy vegetables [41, 51, 64, 83] and fruits [84] is important to note. In Taiwan, schoolchildren aged 6–9 and 10–12 years took 1.6 and 2.0 servings of dark green vegetables daily, respectively, and had a daily fruit intake below 1 serving [84]. Fruit and vegetables were eaten rarely by 56 and 48% of adolescents in Ghana, respectively [64]. In Brazil, 13% of the children met the diet quality index for meat and legumes, while none of the children aged 7–8 years met the diet quality index for vegetables [73]. On the other hand, some studies reported a high intake of fruits rich in vitamin C [51], with seasonal variability of vitamin C-rich food sources reported in another study [45].

**Meal Patterns and Food Choices**

Varied meal patterns were reported among schoolchildren and adolescents. Breakfast was often skipped or rarely eaten by schoolchildren [5, 7, 64, 65, 70, 85] and adolescents [64], especially in rural areas. In Kuala Lumpur, 20% of schoolchildren and adolescents skipped at least one meal a day [85], especially skipping breakfast (12.6%), followed by lunch (6.7%) and dinner, which was not eaten by 4.4% of the students [85]. In Ghana, 32% of adolescents rarely ate breakfast [64]. Where breakfast was eaten, it was often reported to be a plain cup of tea, with milk and groundnuts, millet porridge or leftover food from the previous evening [65]. Breakfast contributed the lowest percentage (10%) of total daily energy in schoolchildren in Kenya [86].

There is an increasing trend towards the consumption of processed foods, especially in urban settings. Foods such as bread, cookies, sweets, soft drinks, ice cream, sweetened beverages, sausages, cheese, sweets and canned foods [49, 56, 87] which are high in sugar, saturated fat, sodium and salt were preferred particularly by the adolescents [39, 49, 53, 88]. School canteens that stock foods with a high energy density further increase the consumption of these foods [14]. This shift is intensified by the rapid replacement of traditional diets with ‘western diets’ [49, 89, 90]. Only one fourth of schoolchildren had a daily consumption of vegetables and fruits in Bahrain, while soda drinks were consumed daily by 50% of the schoolchildren [49]. These foods are eaten mainly away from home and make a large contribution to the overall diet [55]. The extent to which schoolchildren were consuming fast foods and high-energy foods was high, as is illustrated by the high percentage (60–70%) of Malay schoolchildren and adolescents who consumed these foods weekly [85].

**Energy Intake**

The intake of energy was inadequate for the majority of schoolchildren and adolescents [5, 21, 49, 54, 61, 69, 80, 86, 91–93]. The sources of energy, especially for those from poorer households, were limited to a monotonous intake of a few staples. In a peri-urban setting in Kenya, only 17.3% of the schoolchildren aged 4–11 years received adequate energy [5], whereas 50–64% of Bahraini students consumed barely adequate or less than adequate energy [49]. The findings of a study in Accra, Ghana, to compare the nutritional status of children in boarding...
schools with non-boarders, revealed that only 11–27.3% of the children attained the RDA based on age and sex [92]. In Libya, 76% of the schoolchildren attained the RDA for energy [61], and in Brazzaville, Congo, the mean intake of energy for girls (1,998.9 ± 448 kcal) was close to the RDA [94]. In Mexico, 88.0% of the children had adequate amounts of energy [43].

For most of the children, the total energy consumed during the day was not well distributed among the meals. Breakfast contributed the least proportion of the day’s energy because most of the children went to school without breakfast [5, 64, 86]. Among schoolchildren in a peri-urban setting in Kenya, breakfast contributed 10.2% of the total energy requirement instead of the recommended 30% [5]. Similarly, for children in an orphanage in the outskirts of Nairobi City, breakfast contributed only 11.2% of the total daily energy intake [5]. Lunch and the evening meal contributed the largest proportion of the day’s total energy requirement [5, 79, 94]. In Kenyan primary schoolchildren, lunch contributed 44.5% and supper 45.3% of the total energy requirement for the day [5]. In Brazzaville, Congo, the evening meal provided 67.5% of the mean intake of kcal per day [94]. Many of the studies did not report the proportion of children not receiving adequate amounts of energy but reported the mean intake of energy compared to the RDA.

### Macronutrients Intake

#### Protein Intake

On the whole, the findings show that the amount of protein consumed is adequate for the majority of the children and adolescents [43, 49, 59, 69]. Among the Bahraini students, the mean intake of protein exceeded the reference nutrition intake for all age groups and sex by between 1.5 and 2.5 times [49]. In Libya, the mean intake of protein among schoolchildren was 226% of the RDA [61]. In Ghana, schoolchildren, both boarders and non-boarders, attained 100% of the RDA for protein across age groups and sex [92]. The main source of proteins for the majority of children was from plant foods.

#### Fat Intake

Some studies revealed a higher intake of fats than recommended, especially for those children and adolescents from middle- and high-income settings, particularly from urban areas [21, 22], whereas some children and adolescents consumed less fat than the recommended amounts [59]. A study conducted in Accra, Ghana, among children showed that the mean intake of fats was 44.74 ± 20.22 g, which was higher than the RDA for this age group of children [92], and another study in Bahrain indicated that 36–50% of the children exceeded the energy limits for fats, both saturated fats and cholesterol [49]. The intake of fats depends on the foods most commonly consumed. For example, a study conducted in Cape Town reported that the consumption of fats was high or low depending on whether a child’s intake of animal products was frequent or not [22].

Findings show that the amount of protein consumed is adequate for the majority of the children and adolescents.

#### Fibre

Data on fibre intake among school-age children and adolescents from developing countries do not present a specific pattern. Excessive intake of fibre was reported among schoolchildren in some studies [42, 59], while inadequate intake of dietary fibre was reported in others [43, 49, 61, 81]. Considering the recommended WHO DRI of 30 g of fibre per day, the average intake among schoolchildren was as low as 10 g/day in Libya [61] and 14 g/day in Mexico [43] and just adequate (31 g/day) in Cameroon adolescent girls [95]. In addition, daily dietary fibre intake was inadequate in 91% of adolescent girls in Tehran [81]. On the other hand, a median fibre intake of 53 g/day was reported in Beninese school-age children [59], while in Uganda, 84.5% of school girls had a fibre intake above the WHO DRI (30 g) [42].

#### Micronutrient Intake

Micronutrient intake among school-age children in developing countries is generally suboptimal. The most commonly reported vitamins with inadequate intake are vitamins A, B₁, B₂, B₃, B₁₂, folate and β-carotene [13, 42, 45, 46, 54, 79, 95]. At the same time, there is an indication of adequacy of intake of some vitamins, especially of vitamin B₆ [42, 81]. For example, in Ugandan schoolchildren, the average daily intake of vitamins A, C, B₁, B₂, E and folate was 61, 68, 54, 82, 56 and 17% of the RDA, respectively. In the same study, the intake of vitamin B₆ and carotene was above the RDA (145 and 129% of the RDA, respectively) [42]. Inadequacy of vitamin A intake in Ethiopian schoolchildren was as high as 85%, while only 33% of rural and 32% of urban children had sufficient intake of vitamin A in India [54]. In urban Cameroon, the percentage of adolescents with vitamin intake below the
estimated average requirement ranged from about 20% for vitamin A to 80% for folate, especially among girls [64]. In adolescents, an inadequate intake of vitamin B₁₂, folate and vitamin A was reported to be 83.9, 81 and 45.3%, respectively, while on the other hand, vitamin C, B₁, B₂ and B₆ intake was adequate in 95, 97, 83 and 100% of the adolescents, respectively [81].

The intake of minerals among schoolchildren and adolescents in developing countries is also generally suboptimal. Studies showed inadequate intake of iron, calcium and zinc [42, 45, 46, 54, 61, 79, 81, 95, 96] in schoolchildren and adolescents as well as inadequate intake of phosphorus, potassium and magnesium [13] in schoolchildren. For example, in Uganda, the average intake of calcium and zinc was 56 and 70% of the RDA, respectively, while the intake of magnesium, phosphorus and iron was above 100% of the RDA in schoolchildren [42]. In Libyan schoolchildren, calcium and iron intake was 56 and 70% of the RDA, respectively [61]. Adolescents had inadequate intake of calcium (71%) and zinc (95%) in Iran [81]. Inadequate intake of selenium was less commonly reported [96]. Although intake of iron was adequate in some cases, it was mostly derived from plant sources [82] with limited bioavailability.

Discussion

Dietary intake data for children and adolescents are critical to guide appropriate interventions to improve their health and growth. Various methods for collecting data on food consumption are available, but no single best method exists and, therefore, validation of methods needs to be conducted for various countries and contexts. Validation of dietary intake methods was not conducted in most of the studies reviewed, which may have implications for the accuracy and reliability of the findings. Food records, both estimated and weighed, provide accurate quantitative information on food consumed and are considered the gold standard with which other dietary assessment methods are compared [50]. Very few studies used these methods of data collection, probably because of the expense involved. The 24-hour recall was common because it is quick and inexpensive to administer and has high respondent compliance. Whereas the 24-hour recall is appropriate for estimating intake of groups of people, it does not represent the usual consumption. This limitation can be minimised by conducting multiple 24-hour recalls. Few studies conducted more than one 24-hour recall. The popularity of the food frequency questionnaire is due to the fact that it estimates the usual food consumption and may thus be more representative of an individual’s usual intake than a 24-hour recall. The food frequency questionnaire is also relatively inexpensive to conduct and fast to administer, and it is easy to process the data [97].

Children less than 8 years of age have limited cognitive ability to self-report food intake [36]. In most of the reviewed studies, the questionnaires on dietary intake were completed at school by the children with little involvement of the parents and with few of the studies discussing the age of the children as a limitation to data collection. Schoolchildren are known to underreport dietary intake, thus limiting reliability of information [98–100]. Overes-timation of dietary intake has also been observed in self-reported validation studies among school-age children [101, 102]. These limitations of dietary assessment methods need to be kept in mind when interpreting dietary intake data in schoolchildren and adolescents. There is need to validate in-county dietary assessment methods in many of the developing countries.

Energy consumption is not well distributed over the meals of the day. Many children from low socioeconomic backgrounds go to school with a hungry stomach because they do not take breakfast. Breakfast contributes the least and the evening meal the most energy for such children. This may interfere with their level of attention in class and may have negative implications for the achievement of educational objectives and interfere with school enrolment, attendance and performance. This effect has been demonstrated in Ghana [64] and Uganda [91] where taking breakfast was associated with better school performance. This is especially true in situations where no meal is provided at school, which is the case in many developing countries where school lunches are limited to areas of high food insecurity and where world food programmes provide school meals to increase enrolment and attendance [103]. An association between school lunches containing animal source foods that increased the intake of micronutrients and had a positive effect on cognitive development, body composition and growth was demonstrated in Kenya by Neumann and collaborators [9, 104–106] and was pointed out in a systematic review by Kristjansson et al. [12].
Emerging evidence demonstrates that overweight and obesity are increasing in the developing world. Three quarters of the obese population worldwide are projected to be in non-industrialised countries by the year 2025 [107]. The state of being overweight coexists with undernutrition in developing countries [108]. In some parts of Africa, increased weight and fatness affect more children than malnutrition, signifying the double burden of malnutrition [109]. Childhood obesity is increasingly becoming a public health problem in the developing world because it is associated with serious health problems and the risk of premature illness and death later in life. Consequently, the prevalence of non-communicable diseases such as hypertension, cardiovascular diseases, type 2 diabetes and osteoarthritis is becoming a public health concern.

Eating patterns and diet quality have emerged as important determinants of obesity in children [21]. Obesity is thought to be associated with children’s increased exposure to calorie-dense foods and sedentary lifestyle choices [110]. Although some genetic predispositions contribute to childhood obesity, its rapid increase in genetically stable populations indicates the importance of social and environmental factors in causing obesity. Strong associations between childhood obesity and daily lifestyle factors are reported, suggesting that many of the causes are environmental [111].

Some of the studies reviewed showed that children and adolescents, particularly those from higher socioeconomic status and urban areas, tend to consume more than adequate amounts of energy, confirming the nutrition transition taking place in the developing countries. A large proportion of the energy consumed is obtained mainly from the increased intake of high-calorie foods [19, 21, 57], which is associated with the development of adiposity and increases the risk of being overweight or obese as an adult in the future [18]. Typical urban lifestyles, technological advances and better economic status are accompanied by increased access to and consumption of energy-dense foods and sedentary activities [112, 113]. Consequently, children and adolescents have a positive energy balance and increased adiposity [114, 115].

In some parts of Africa, increased weight and fatness affect more children than malnutrition, signifying the double burden of malnutrition.

The findings of this literature review confirm the changing trends in dietary patterns of children and adolescents [14, 116]. The consumption of soda and other sweetened beverages and fast foods [19, 21] is a risk factor for overweight and obesity [62]. Many children’s and adolescents’ diets are inadequate with respect to vegetable and fruit intake and, thus, are most likely to be low in fibre and consequently associated with a high waist circumference and, therefore, overweight and obesity [19, 66]. Low-intensity physical activity is associated with obesity in adolescents [96].

Conclusions

The dietary intake in the developing countries is interpreted based on global references and food tables because a majority of the countries do not have country-specific reference tables. Therefore, there is a need for countries to develop appropriate and relevant country-specific reference and food bases.

On the whole, the diets consumed by children and adolescents in the developing countries are inadequate in terms of energy and fats and a majority of the micronutrients. The diets are also limited in diversity and meal patterns are inappropriate, consequently interfering with the distribution of nutrients over the day. On the other hand, there are some children who consume more than adequate amounts of calories and high-energy-dense foods, which contributes to the increasing occurrence of overweight and obesity in schoolchildren and adolescents in developing countries. Interventions to mitigate this trend should therefore also be prioritised even as undernutrition is emphasised.

In view of the fact that many children go to school without breakfast, interventions for dietary improvements should consider providing school meals for improved health and performance of the children. There is a need for nutrition education for school management, children, parents and the community at large to sensitise them on healthy eating habits, especially to avoid the consumption of high-calorie-dense foods and to choose healthy and diverse diets. School management should also ensure that only healthy foods are sold at school and children and adolescents are encouraged to participate in physical activities to tame the increasing levels of overweight and obesity in this population.

Disclosure Statement

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Ochola/Masibo
Dietary Intake of Schoolchildren and Adolescents in Developing Countries


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Infants and children are especially vulnerable to mycotoxin exposure, mostly because of a lower detoxification capacity, rapid growth and high intake of food and water per kg body weight.

**Key insights**

The four main mycotoxins that influence human health are the aflatoxins, fumonisins, deoxynivalenol and zearalenone. These compounds are thought to alter the cellular and biochemical functions of the intestine, resulting in micronutrient deficiencies, systemic immune activation and impaired nutrient uptake. In Africa, the majority of the population are subsistence farmers who grow, store and prepare their own staple foods. Consequently, a large proportion of infants and young children receive these staple foods that are contaminated with mycotoxins.

**Current knowledge**

Regardless of high exposure levels and the burden of mycotoxins on the health economics of various low-income countries, mycotoxins have been largely overlooked from a public health perspective. Thus, knowledge of the effects of food-borne mycotoxins on the growth and health of infants and young children is critical for overcoming this public health challenge.

**Practical implications**

Results from aflatoxin studies indicate that this toxin can cross the placenta and is present in the umbilical cord and in breast milk. Furthermore, there are seasonal differences in the levels of aflatoxin in cord blood and breast milk. Due to low breastfeeding rates across Africa, there was a significant association between weaning status and aflatoxin exposure levels. Higher aflatoxin exposure (both in utero and in early life) was strongly associated with stunting and/or underweight. Children with fumonisin intakes exceeding the provisional maximum tolerable daily intake were significantly shorter and lighter. Very little is known about the effects of deoxynivalenol and zearalenone on childhood growth and development.

**Recommended reading**

Mycotoxin Exposure and Infant and Young Child Growth in Africa: What Do We Know?

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Centre of Excellence for Nutrition (CEN), North-West University, Potchefstroom, South Africa

Key Messages
- There is limited information available on the presence of mycotoxins (aflatoxin (AF), fumonisin (FB), deoxynivalenol (DON) and zearalenone (ZEA)) and the exposure levels to these mycotoxins in infants and young children in Africa.
- Various animal and human studies indicate that AF cross the placenta during pregnancy, are present in the umbilical cord and are in breast milk; however, very little is known about the effects of other mycotoxins.
- AF influence infant and young child growth in various phases of growth, but it is not clear what the influence of other mycotoxins is on growth.

Key Words
Mycotoxin · Aflatoxin · Fumonisins · Deoxynivalenol · Zearalenone · Stunting · Wasting · Underweight · Africa · Infants · Children

Abstract
Introduction: Infant and young child (IYC) growth impairment remains a public health problem in Africa partly because infants are exposed to staple foods (contaminated with mycotoxins) at an early age. Understanding the role of mycotoxins in IYC growth is vital, and this paper systematically reviews the available knowledge. Methods: Studies were searched and included if they provided information on African IYC mycotoxin exposure rates and/or growth. Studies were excluded if subjects were older than 15 years, if they were animal studies or focusing on other mycotoxins. Relevant search words were included in search strings. Eight reviews were identified and reference lists scrutinised for additional studies. Results: Ten studies were included; 8 focused on aflatoxin (AF), 2 on fumonisin (FB) and none on deoxynivalenol (DON) and zearalenone (ZEA). AF exposure prevalence reached 100% with levels at 40.4 pg/mg. AF was present in umbilical cords indicating that AF crosses the placenta. Maternal exposure levels were correlated with breast milk levels. The highest levels of serum AF (mean 32.8 pg/mg) were measured in Benin and Togo with 5.4% reaching levels higher than 200 pg/mg. At the end of weaning, children had similar prevalence and exposure levels as adults. Results also indicated that infants with higher levels of maternal exposure had significantly lower height-for-age z-scores (HAZ scores), although there was no significant association between cord AF and infant HAZ scores or AF in cord blood and HAZ scores. Significantly higher mean maternal AF levels related to lower weight-for-age z-scores (WAZ scores) were reported, and infants with higher levels of maternal exposure had significantly lower WAZ scores that de-
Introduction

Growth impairment is a large public health problem in Africa with many countries reporting a high prevalence of stunting and underweight in children (table 1) [1]. The combined effect of intrauterine growth restriction, infant and young child (IYC) stunting, underweight and wasting was responsible for millions of deaths in Africa during the last decade [2].

Growth faltering can have a detrimental impact on the long-term physical and cognitive development, and African children have for decades been especially vulnerable to growth faltering due to famine, drought, political instability and poverty. These factors inevitably lead to food insecurity resulting in poor nutritional intake. Infants are also often given complementary food at a young age, and weaning foods usually are household staples. Staple foods in the majority of African countries are predominantly maize and groundnuts which are vulnerable to fungi [3].

Mycotoxins are low-molecular-weight metabolites that are produced by fungi [4]. Although there are approximately 300–400 mycotoxins [5], four are known to influence human health [aflatoxin (AF), fumonisin (FB), deoxynivalenol (DON) and zearalenone (ZEA)] [6]. Aspergillus mold strains produce AF and ochratoxin, while Fusarium mold strains produce FB, DON and ZEA [6]. Table 2 summarises the most prevalent mycotoxins found in Africa.

Although various studies have been conducted to determine the effect of mycotoxin exposure on growth, a lack of suitable biomarkers has made it difficult to determine exposure and risk. However, various biomarkers have recently been tested and validated, potentially improving risk assessment [7].

The exact mechanisms by which mycotoxins influence IYC health are not currently known. A conceptual framework based on the known mechanisms of action and their effect on infant growth has been suggested; however, more research is urgently needed to completely understand the mechanisms and their individual downstream pathways [6]. It has been suggested that AF and DON inhibit protein synthesis leading to altered intestinal architecture, inhibition of intestinal regeneration, impaired tight junctions and glucose-galactose malabsorption [6]. DON exposure leads to an increase in systemic cytokines. FB lastly cause a decrease in complex sphingolipids. It is thus suggested that these mechanisms ultimately lead to zinc deficiency (AF), systemic immune activation (AF, DON and FB), impaired nutrient uptake (AF and DON) and food refusal (DON) [6].

Knowing the impact food-borne mycotoxins have on growth impairment and ultimately the health of infants and young children is of the utmost importance. This is especially true since the majority of the population in Africa are subsistence farmers and thus grow, store and prepare their own staple foods [3]. Unfortunately, a very limited number of epidemiological studies have been conducted, and little is known about the impact of food-borne mycotoxins on IYC health [3]. This paper systematically

<table>
<thead>
<tr>
<th>Country</th>
<th>Stunting prevalence, %</th>
<th>Underweight prevalence, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>15.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Angola</td>
<td>29.2</td>
<td>15.6</td>
</tr>
<tr>
<td>Benin</td>
<td>44.7</td>
<td>20.2</td>
</tr>
<tr>
<td>Botswana</td>
<td>31.4</td>
<td>11.2</td>
</tr>
<tr>
<td>Burundi</td>
<td>57.7</td>
<td>35.2</td>
</tr>
<tr>
<td>Cameroon</td>
<td>36.4</td>
<td>16.6</td>
</tr>
<tr>
<td>Congo</td>
<td>31.2</td>
<td>11.8</td>
</tr>
<tr>
<td>DRC</td>
<td>45.8</td>
<td>28.2</td>
</tr>
<tr>
<td>Egypt</td>
<td>30.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>50.7</td>
<td>34.6</td>
</tr>
<tr>
<td>Ghana</td>
<td>28.6</td>
<td>14.3</td>
</tr>
<tr>
<td>Kenya</td>
<td>35.2</td>
<td>16.4</td>
</tr>
<tr>
<td>Lesotho</td>
<td>45.2</td>
<td>16.6</td>
</tr>
<tr>
<td>Malawi</td>
<td>47.8</td>
<td>13.8</td>
</tr>
<tr>
<td>Niger</td>
<td>54.8</td>
<td>39.9</td>
</tr>
<tr>
<td>Nigeria</td>
<td>41.0</td>
<td>26.7</td>
</tr>
<tr>
<td>Rwanda</td>
<td>51.7</td>
<td>18.6</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>37.4</td>
<td>25.4</td>
</tr>
<tr>
<td>Sudan</td>
<td>37.9</td>
<td>31.7</td>
</tr>
<tr>
<td>Uganda</td>
<td>38.7</td>
<td>16.7</td>
</tr>
</tbody>
</table>

DRC = Democratic Republic of the Congo.
reviews the current available knowledge regarding the different mycotoxins in terms of growth retardation of infants and young children living in low- and middle-income countries in Africa. Gaps are identified and further research is suggested.

**Methods**

A systematic search was conducted in four major databases including Medline (PubMed), EBSCOhost Online Research Databases, Google Scholar and HighWire Press. Studies were included if they provided information on mycotoxin exposure rates (AF, FB, DON and/or ZEA) in one or more African countries (regardless of the region). Studies were further included if research was conducted on IYC mycotoxin exposure and growth faltering.

Studies were excluded if the research was conducted in non-African countries, if they were conducted before the year 2000 and if they were conducted on parameters other than child growth faltering. Animal studies and those that investigated the effect of other mycotoxins were also excluded.

The following search words (amongst others) were included in the search strings: mycotoxin, aflatoxin, fumonisin, deoxynivalenol, zearalenone, Africa, sub-Sahara, growth, stunting, wasting, underweight and malnutrition. In addition to this, 8 recent reviews conducted on related topics were identified and their reference lists were scrutinised for additional studies. Results on different exposure levels for the four mycotoxins and their effect on IYC growth faltering were tabulated.

**Results**

A total of 55 studies were initially identified (fig. 1). Of these, 41 studies were excluded for the following reasons: (1) not conducted in Africa; (2) not focusing on growth impairment; (3) animal study, and (4) subjects too old for inclusion. In total, 10 studies were included; 8 focused on AF, 2 on FB and none investigated DON and ZEA.

**Aflatoxin**

There are six major types of AFs (table 2), of which AFB1 is the most toxic [5, 6]. It is estimated that approximately 4.5 billion of the world’s population is exposed to AF [8]. This mycotoxin occurs in tropical regions where the humidity and the temperature are high [9].

**Table 2. Summary of the most prevalent mycotoxins in Africa**

<table>
<thead>
<tr>
<th>Mycotoxins</th>
<th>AF</th>
<th>FB</th>
<th>DON</th>
<th>ZEA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Types</strong></td>
<td>B1, B2, G1, G2, M1, M2</td>
<td>FB1, FB2, FB3</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Accumulation</strong></td>
<td>accumulate after harvest</td>
<td>location, climate, susceptibility of the plant to fungal invasion, insect damage, crop stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary food sources</strong></td>
<td>nuts, spices, maize (corn), cacao, coffee, rice, milk</td>
<td>maize (corn)</td>
<td>wheat, barley, maize (corn)</td>
<td>maize (corn), wheat, barley, sorghum</td>
</tr>
<tr>
<td><strong>Solubility</strong></td>
<td>fat soluble</td>
<td>water soluble [16]</td>
<td>partially water soluble</td>
<td></td>
</tr>
<tr>
<td><strong>TDI, μg/kg bw/day</strong></td>
<td>none</td>
<td>2 [32]</td>
<td>100 [33]</td>
<td></td>
</tr>
<tr>
<td><strong>PMTDI, μg/kg bw/day</strong></td>
<td>2</td>
<td>1</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td><strong>Urine biomarker</strong></td>
<td>AF-guanine adduct, AFM1, AFP1, AFQ1 and AFB1-mercapturic acid [34]</td>
<td>FB1</td>
<td>DON glucuronide, DON + de-epoxydeoxynivalenol (DON-1)</td>
<td>ZEA + α-zearalenol (α-ZOL) + β-zearalenol (β-ZOL)</td>
</tr>
<tr>
<td><strong>Blood biomarker</strong></td>
<td>Serum/plasma AF-alb adduct [34]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Breast milk biomarker</strong></td>
<td>AFM1 [5]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TDI = Tolerable daily intake; bw = body weight.
Maternal and infant exposure occurs at extremely high levels in various African countries, including Ghana [10], Benin [11, 12], Togo [11], Egypt [13, 14], Guinea [14] and the Gambia [15] (table 3). Various aspects of exposure were studied including maternal consumption [10, 15], umbilical cords [15], breast milk [13, 14] and IYC consumption [11, 12, 14–17].

Exposure

Two studies investigated maternal AF exposure in Ghana (n = 755) [10] and the Gambia (n = 119) [15] (table 3). Although both reported 100% exposure prevalence, maternal serum AF exposure was much higher in the Gambia (40.4 pg/mg) compared to Ghana (10.9 pg/mg).

Another study [15] measured serum AF levels in umbilical cords to determine if AF crosses the placenta. The study reported lower serum AF levels in cord samples compared to mothers’ serum AF levels (10.1 pg/mg and 40.4 pg/ml, respectively). It was, however, clear that AF is transported from the mother to the infant, increasing the already vulnerable infant’s exposure [15]. Lastly, the authors identified significantly increased serum AF levels in cord blood during April to July compared to December to March or August to November [15] (table 3).

Because AF are lipophilic, maternal AF consumption can result in the accumulation of AF and its metabolites in breast milk [13]. It is, however, difficult to determine the average daily infant AF exposure from breast milk because maternal exposure varies daily, and fat content and total milk volume consumed per feed and within feeds vary [14]. Polychronaki et al. [14] found AFM$_1$ (13.5 pg/ml) in the breast milk of 36% (n = 138) of their participants in Egypt. They further found an increase in AFM$_1$ breast milk levels during different seasons (April to July) [14], indicating the importance of seasonal differences.

Infants and children are especially vulnerable to mycotoxin exposure, mostly because of a lower detoxification capacity, rapid growth and high intake of food and water per kg body weight [18]. In a study conducted in Benin and Togo (West Africa), extremely high levels of serum AF were measured (table 3) amongst children [16]. The geometric mean exposure of these children was 32.8 pg/mg, with at least 1 child exposed to 1,064 pg/mg [16]. Also, 5.4% of the participating infants had exposure levels higher than 200 pg/mg. Serum AF levels were lowest among infants (<12 months) but increased as age increased to 24–36 months of age, when exposure levels reached a plateau [16].

Because of poor exclusive breastfeeding rates reported all over Africa, it is important to understand the impact of complementary feeding and weaning on the exposure levels of these infants. Gong et al. [16] conducted a multivariable analysis to determine the impact weaning status has on exposure levels. Results indicated a significant association with serum AF and that exposure was at least two-fold higher amongst those not breastfed compared to those exclusively or partially breastfed. This suggests that weaning status rather than age is associated with high exposure levels [16].

Infants and children are especially vulnerable to mycotoxin exposure, mostly because of a lower detoxification capacity, rapid growth and high intake of food and water per kg body weight.

In their study, Gong et al. [16] also found a weak positive correlation between child maize consumption and serum AF levels [16]. The authors concluded that this was due to a number of reasons including (1) poor maize intake quantification methods, (2) the influence of AF reduction practices such as maize washing and sorting; (3) other AF dietary components, and (4) the fact that the AF-alb marker integrates exposure over a different period than the dietary assessment method reflects [16].
<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Sample size, n</th>
<th>Mycotoxin tested</th>
<th>Method</th>
<th>Age group</th>
<th>Exposure levels</th>
<th>Prevalence n/total n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Ghana</td>
<td>755</td>
<td>AF</td>
<td>Serum AFB&lt;sub&gt;1&lt;/sub&gt;-lysine adducts</td>
<td>Mothers</td>
<td>Mean (range), pg/mg: 10.9 (0.44–268.7)</td>
<td>755/755 (100.0)</td>
<td></td>
</tr>
<tr>
<td>11 Benin and Togo</td>
<td>480</td>
<td>AF</td>
<td>Serum AF-alb adducts</td>
<td>Children (9–60 months)</td>
<td>Geometric mean (range), pg/mg: 32.8 (5.0–1,064.0) Fully weaned infants: 45.6 (38.8–53.7) Partially breastfed infants: 18.0 (15.2–21.3)</td>
<td>475/479 (99.2)</td>
<td></td>
</tr>
<tr>
<td>16 Benin and Togo</td>
<td>479</td>
<td>AF</td>
<td>Serum AF-alb adducts</td>
<td>Infants and children (0–60 months)</td>
<td>Geometric mean (range), pg/mg: 32.8 (25.3–42.5)</td>
<td>475/479 (99.9)</td>
<td></td>
</tr>
<tr>
<td>12 Benin</td>
<td>200</td>
<td>AF</td>
<td>Serum AF-alb adducts</td>
<td>Infants (16–37 months)</td>
<td>Geometric mean AF-alb, pg/mg:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Weaned</td>
<td>February 54.4 October 99.4 Not weaned 8.9 24.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Guinea</td>
<td>50</td>
<td>AF</td>
<td>Urinary AF metabolites (AFM&lt;sub&gt;1&lt;/sub&gt;, AFB&lt;sub&gt;1&lt;/sub&gt;, AFB&lt;sub&gt;2&lt;/sub&gt;, AFG&lt;sub&gt;1&lt;/sub&gt;, AFG&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>Infants (24–48 months)</td>
<td>Geometric mean (95% CI), pg/ml: AFB&lt;sub&gt;1&lt;/sub&gt;: 13.2 (11.8–14.6) AFB&lt;sub&gt;2&lt;/sub&gt;: 0.2 (0.2–0.3) AFG&lt;sub&gt;1&lt;/sub&gt;: 26.0 (24.5–27.7) AFG&lt;sub&gt;2&lt;/sub&gt;: 0.57 (0.46–0.70) AFM&lt;sub&gt;1&lt;/sub&gt;: 2.7 (2.5–2.8)</td>
<td>AFB&lt;sub&gt;1&lt;/sub&gt;: 1/50 (2.0) AFB&lt;sub&gt;2&lt;/sub&gt;: 5/50 (10.0) AFG&lt;sub&gt;1&lt;/sub&gt;: 2/50 (4.0) AFG&lt;sub&gt;2&lt;/sub&gt;: 12/50 (24.0) AFM&lt;sub&gt;1&lt;/sub&gt;: 4/50 (8.0)</td>
<td></td>
</tr>
<tr>
<td>17 Kenya</td>
<td>242</td>
<td>AF</td>
<td>Maize consumption</td>
<td>Children (3–36 months)</td>
<td>Geometric mean AF-alb, pg/mg:</td>
<td>198/242 (82)</td>
<td></td>
</tr>
<tr>
<td>14 Egypt</td>
<td>50</td>
<td>AF</td>
<td>AFB&lt;sub&gt;1&lt;/sub&gt; levels in breast milk</td>
<td>Lactating mothers</td>
<td>Mean (range), pg/ml: January: 8.0 (4.2–108.0) February: 12.0 (4.8–275.0) March: 18.0 (5.0–181.0) April: 36.0 (5.7–889.0) May: 40.0 (4.6–609.0) June: 28.0 (4.5–228.0) July: 60.0 (6.3–497.0) August: 15.0 (4.5–127.0) September: 14.0 (4.3–63.0) October: 13.0 (5.3–110.0) November: 28.0 (4.9–360.0) December: 12.0 (9.2–61.0)</td>
<td>12/50 (24.0) 8/49 (16.3) 28/50 (56.0) 20/50 (40.0) 23/26 (88.5) 25/26 (96.2) 24/26 (92.3) 22/29 (75.9) 24/29 (82.3) 22/29 (75.9) 21/29 (72.4) 16/50 (32.0)</td>
<td></td>
</tr>
<tr>
<td>14 Egypt</td>
<td>50</td>
<td>AF</td>
<td>Urinary AF metabolites (AFM&lt;sub&gt;1&lt;/sub&gt;, AFB&lt;sub&gt;1&lt;/sub&gt;, AFB&lt;sub&gt;2&lt;/sub&gt;, AFG&lt;sub&gt;1&lt;/sub&gt;, AFG&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>Infants (24–48 months)</td>
<td>Geometric mean (95% CI), pg/ml: AFB&lt;sub&gt;1&lt;/sub&gt;: 26.6 (16.3–42.9) AFB&lt;sub&gt;2&lt;/sub&gt;: 0.8 (0.5–1.3) AFG&lt;sub&gt;1&lt;/sub&gt;: 26.6 (23.3–30.6) AFG&lt;sub&gt;2&lt;/sub&gt;: 1.1 (0.7–1.7) AFM&lt;sub&gt;1&lt;/sub&gt;: 16.3 (10.1–26.6)</td>
<td>AFB&lt;sub&gt;1&lt;/sub&gt;: 8/50 (16.0) AFB&lt;sub&gt;2&lt;/sub&gt;: 29/50 (58.0) AFG&lt;sub&gt;1&lt;/sub&gt;: 1/50 (2.0) AFG&lt;sub&gt;2&lt;/sub&gt;: 18/50 (36.0) AFM&lt;sub&gt;1&lt;/sub&gt;: 32/50 (64.0)</td>
<td></td>
</tr>
<tr>
<td>13 Egypt</td>
<td>388</td>
<td>AF</td>
<td>AFB&lt;sub&gt;1&lt;/sub&gt; levels in breast milk</td>
<td>Lactating mothers</td>
<td>Median (IQR), pg/ml: 13.5 (10.3–21.43)</td>
<td>139/388 (36.0)</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3 (continued)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Sample size, n</th>
<th>Mycotoxin tested</th>
<th>Method</th>
<th>Age group</th>
<th>Exposure levels</th>
<th>Prevalence n/total n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>The Gambia</td>
<td>(1) 119</td>
<td>AF</td>
<td>(1) Maternal blood, AF-alb during pregnancy (2) Cord AF-alb (3) Infant blood AF-alb at 16 weeks of age</td>
<td>(1) Pregnant women (2) Cord (3) Infants (16 weeks)</td>
<td>Geometric mean (IQR), pg/mg: (1) Maternal: 40.4 (4.8–260.8) (2) Cord: 10.1 (5.0–189.6) (3) Infant: 8.7 (5.0–30.2)</td>
<td>(1) 119/119 (100.0) (2) 48/99 (48.5) (3) 13/118 (11.0)</td>
</tr>
<tr>
<td>[35] Tanzania</td>
<td>254 FB</td>
<td>Modelling maize consumption data (g/kg bw/day) with FB contamination patterns</td>
<td>Participants were stratified according to 50th, 75th, 90th and 97th percentile of maize consumption</td>
<td>Infants (6 months)</td>
<td>2005: Contamination range, μg/kg: Total 26 (23–30)</td>
<td>50th 0.47 (0.41–0.54)</td>
<td>75th 2.14 (1.55–2.84)</td>
</tr>
<tr>
<td>[21] Tanzania</td>
<td>131/191 FB</td>
<td>FB&lt;sub&gt;1&lt;/sub&gt; + FB&lt;sub&gt;2&lt;/sub&gt; + FB&lt;sub&gt;3&lt;/sub&gt; levels in cooked maize and habitual maize consumption</td>
<td>Infants (6–8 months)</td>
<td>Median (range), μg/kg bw/day: 0.48 (0.003–28.838)</td>
<td>131/191 (68.9)</td>
<td></td>
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</tr>
</tbody>
</table>

pg/mg = pg 2 AF-lysine equivalents per mg of albumin; pg/ml = pg AFM<sub>1</sub> equivalents per ml of breast milk; IQR = interquartile range. * p < 0.05; ** p < 0.001. * A total of 191 infants were included in the study, while 131 consumed FB-contaminated maize (statistics were included on the 131 FB-exposed infants).
Table 4. Mycotoxin studies conducted during the last decade on growth faltering

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Sample size, n</th>
<th>Mycotoxin tested</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Benin and Togo</td>
<td>480</td>
<td>AF</td>
<td>Children (9–60 months) from 16 villages in 4 geographic zones were included. Anthropometric measures were taken, z-scores calculated and AF-alb adducts tested</td>
<td>Association: AF-alb adduct and HAZ** AF-alb adduct and WAZ** AF-alb adduct and WHZ*</td>
</tr>
<tr>
<td>12</td>
<td>Benin</td>
<td>200</td>
<td>AF</td>
<td>Fifty children from 4 villages (2 high-contamination risk areas and 2 low-contamination risk areas) Measurements were conducted in February and October</td>
<td>Mean AF-alb and height increase after 8 months: Exposure&lt;sup&gt;a&lt;/sup&gt; Mean height (SD), cm Lower quartile 5.9 (5.2–6.6) Mid-lower quartile 5.3 (4.8–5.9) Mid-upper quartile 4.8 (4.4–5.2) Upper quartile 4.2 (3.9–4.6)</td>
</tr>
<tr>
<td>16</td>
<td>Benin and Togo</td>
<td>479</td>
<td>AF</td>
<td>A cross-sectional study that included children of weaning age. Anthropometric measures were taken, z-scores calculated and AF-alb adducts tested</td>
<td>Association: AF-alb adduct and HAZ** AF-alb adduct and WAZ** AF-alb adduct and WHZ</td>
</tr>
<tr>
<td>15</td>
<td>The Gambia</td>
<td>138</td>
<td>AF</td>
<td>Infants were included at birth and followed up monthly for 12 months Serum AF-alb adduct levels were measured in maternal blood during pregnancy, in cord blood and in infants at 16 weeks of age</td>
<td>Maternal AF-alb levels and infant weight, multiple regression coefficient: Maternal AF-alb and infant WAZ: –0.249 Maternal AF-alb and infant WAZ profile over time: –0.004** Cord AF-alb and infant WAZ: –0.024 Maternal AF-alb and infant WAZ at week 16: –0.355 Maternal AF-alb levels and infant height: Maternal AF-alb and HAZ: –0.207* Maternal AF-alb and HAZ profile over time: –0.008** Cord AF-alb and infant HAZ: –0.049 Maternal AF-alb and HAZ at week 16: –0.558*</td>
</tr>
<tr>
<td>17</td>
<td>Kenya</td>
<td>242</td>
<td>AF</td>
<td>Maize was collected from households with children aged 3–36 months and analysed Anthropometric measures of the children were taken</td>
<td>Intake from malnourished&lt;sup&gt;b&lt;/sup&gt; children: Wasted children: 53.8% AF consumers vs. 27.7% non-AF consumers* Stunted children: 32.4% AF consumers vs. 28.9% non-AF consumers Underweight children: 41.4% AF consumers vs. 27.3% non-AF consumers</td>
</tr>
<tr>
<td>21</td>
<td>Tanzania</td>
<td>131</td>
<td>FB</td>
<td>FB&lt;sub&gt;1&lt;/sub&gt; + FB&lt;sub&gt;2&lt;/sub&gt; + FB&lt;sub&gt;3&lt;/sub&gt; levels in cooked maize and habitual maize consumption</td>
<td>LE HE Mean (SD) Mean (SD) WAZ −0.32 (1.00) −1.77 (1.17)* LAZ −0.97 (1.05) −1.60 (1.13)* WLZ 0.46 (1.01) 0.44 (1.27)</td>
</tr>
</tbody>
</table>

LAZ = Length-for-age z-score; WLZ = weight-for-length z-score; LE = low-exposure group; HE = high-exposure group. * p < 0.05; ** p < 0.01. <sup>a</sup> Lower quartile: <23.3; mid-lower quartile: 23.3–53.0; mid-upper quartile: 53.0–101.5; upper quartile >101.5 pg/mg. <sup>b</sup> According to the Welcome classification.
Infant Growth
Five studies [11, 12, 15–17] (conducted in Benin, Togo, the Gambia and Kenya) investigated the role of AF in infant growth (table 4).

Gong et al. [11] reported a strong inverse association between serum AF and IYC growth [weight-for-age z-scores (WAZ scores), height-for-age z-scores (HAZ scores) and weight-for-height z-scores (WHZ scores)]. The study revealed that stunted and/or underweight children were exposed to 30–40% higher mean serum AF levels. Subsequently, the authors conducted an 8-month longitudinal study and reported strong negative associations between serum AF and height and weight increase of children [16]. The following year, Gong et al. [12] reported that the highest quartile of AF-alb adducts was associated with a 1.7-cm reduction in height compared to the lowest quartile.

Okoth and Ohingo [17] analysed weaning flours from 242 households (Kenya) with children aged 3–36 months for AF. Anthropometric measures of the children were also taken and compared to maize AF consumption levels. Although only 28% (n = 68) of non-wasted children were from households with AF-contaminated flour, approximately 54% (n = 131) of the wasted children were from households with detectable AF in the flour. There was a significant association between AF exposure and wasting (WAZ score), but not between AF exposure and stunting (HAZ score) and between AF exposure and underweight (WHZ score) (table 4). AF were also more frequently detected in the flour of stunted and underweight children compared with normal children, even if values were not significantly different [17].

In 2007, Turner et al. [15] conducted a study in the Gambia that included in utero exposure levels and reported a significant association between maternal exposure and impaired infant growth (especially during the first year of life) (table 3). They further reported that growth faltering in these children occurred during the weaning process and compared maternal AF levels with infant growth rates (table 4). After adjusting for covariates, significantly higher mean maternal serum AF levels were associated with lower WAZ scores (table 4). When comparing data from maternal AF and infant age (in weeks), it was found that infants with higher levels of maternal exposure had a significant WAZ score decrease over age (table 4). Cord AF levels, however, had no effect on infant WAZ scores (table 4).

In terms of the HAZ score, a significantly higher level of mean maternal AF levels was related to lower HAZ scores (table 4), with no significant association between cord AF and infant HAZ scores [15].

Fumonisins
FB were first identified by Gelderblom et al. [19] in 1988 and include three major FB, of which FB1 is the most abundant (table 2) [9]. Maize is infected in the field, and the majority of toxin is present at the time of harvest, making the control of FB more focused on pre-harvest practices and on the subsequent effects of processing and preparation of foodstuffs [20].

Exposure
Very little is known about maternal and infant FB exposure, mostly due to the lack of validated biomarkers. Two studies, both conducted in Tanzania, were included in the review (table 3).

Kimanya et al. [21] reported that 12% (n = 26) of infants exceeded the provisional maximum tolerable daily intake (PMTDI) of 2 mg · kg–1 body weight [21]. Maize consumption and FB contamination patterns in rural South Africa and Tanzania are similar [22]. The average per capita maize consumption can be as high as 397 g/day in South Africa [23] and as high as 356 g/day in Tanzania [24]. FB contamination concentrations in home-grown maize are up to 10,140 mg/kg in South Africa [23] and up to 11,048 mg/kg in Tanzania [25].

IYC Growth
Only 1 study investigated the relationship between IYC growth and FB exposure (table 4). It was found that children with FB intakes greater than the PMTDI were significantly shorter (1.3 cm) and lighter (328 g) than children with FB intakes less than the PMTDI [25].

Very little is known about maternal and infant FB exposure, mostly due to the lack of validated biomarkers.

Deoxynivalenol
DON is the most frequently encountered mycotoxin in regions of the world with a mild climate (table 2). It contaminates wheat, maize and barley, and due to its stability during processing, exposure is predicted to be frequent [26].

This review found that, to date, there have been no epidemiological studies in humans conducted in Africa looking at maternal and infant DON exposure. DON has, however, been associated with diarrhoea and vomiting [6], impaired gastric emptying and gut mobility [6], reduced weight gain [27] and impaired immune function in...
humans [28]. However, because of the lack of valid biomarkers, the effects of DON exposure on growth in children have not yet been studied [28]. Nevertheless, it is expected that (based on animal studies) DON has a negative effect on growth because of decreased food intake and reduced weight gain.

Animal studies found that DON crosses the placenta [29]; it is therefore likely that in utero exposure to DON will occur in humans as well. This is mostly because the detoxification capacity of the foetus has not been fully developed at a time of rapid growth and cell turnover; thus, pregnancy may represent a critical window for DON exposure [26]. Seen in this light, it is vital that more epidemiological studies are conducted in terms of maternal and infant DON exposure as well as its effect on IYC growth.

Zearalenone

ZEA originates from *Fusarium graminearum* and infects maize, wheat, barley and sorghum. Very little is known concerning ZEA and infant and maternal exposure levels in Africa, once again mostly due to the lack of valid biomarkers. However, the primary symptoms of ZEA toxicosis include nausea, vomiting and diarrhoea [29]. All three of these symptoms could influence IYC growth negatively (especially in terms of food refusal and weight loss), and therefore it is assumed that there might be associations between ZEA exposure and IYC growth impairment. Furthermore, ZEA exposure in animal studies has been associated with reduced body weight and histopathological changes in the liver and the kidneys [30]. For these reasons, it is imperative that more research is conducted on infant and maternal ZEA exposure and also its effect on IYC growth.

**Discussion**

Various studies have been conducted looking at different AF exposure measures (infant serum levels, infant consumption, in utero exposure and cord AF levels) and infant growth (WAZ, HAZ and WHZ scores). Exposure levels in the different studies ranged from 36 to 100% and increased during May to November. There were strong inverse associations between all AF exposure measures and IYC WAZ, HAZ and WHZ scores.

Only 1 study looked at infant FB consumption and also reported that significant IYC exposure is connected with lower WAZ and HAZ scores. However, infant consumption is always difficult to accurately measure (in terms of portion sizes and frequency of consumption); therefore, more studies using biomarkers (newly validated and thus available) should be conducted on the abovementioned exposure measures. Since FB has been associated with neural tube defects and growth impairment (animal studies), determining its impact in epidemiological studies is vital. Extremely high levels of FB in maize have been documented in rural areas in South Africa, Kenya and Tanzania, where residents are predominantly subsistence farmers.

Furthermore, no epidemiological studies have been conducted looking at DON or ZEA and maternal and IYC exposure or growth impairment. This is due to a lack of valid biomarkers and, thus, research should focus on the development and validity of biomarkers to accurately measure DON and ZEA. However, DON and ZEA levels in maize samples can be determined and, therefore, exposure levels and the impact on growth should be measured in terms of maternal and IYC consumption exposure as has been done on FB in Tanzania.

Based on the current limited information that is available on mycotoxin risk assessment, it is clear that epidemiological as well as additional basic research is urgently needed to further understand the role of mycotoxins in IYC exposure and growth. The high prevalence and exposure levels that have been reported by various studies conducted in Africa as well as the persistent growth faltering found in Africa suggest that child growth and development could be critically affected by mycotoxin exposure. However, to date very little attention has been given to this problem and, hence, very little is known about the mechanism(s) involved and the size of the problem.

Regardless of high exposure levels in various African countries and regardless of the fact that the effects of mycotoxins have a large burden on low-income countries’ health economy, mycotoxins have mostly not been prioritised from a public health perspective [3]. There are various reasons for this, including the lack of knowledge, poor communication between researchers, health professionals and policy makers and perceived low value of mycotoxin reduction interventions [3].

Since FB has been associated with neural tube defects and growth impairment, determining its impact in epidemiological studies is vital.
Based on the results found in this study, the following research is thus suggested:

- basic research in understanding the mechanisms and their individual downstream pathways involved [6];
- basic research in developing and validating biomarkers for measuring mycotoxin exposure;
- because mycotoxin exposure may be an indication of poor diet quality, research must address this as a potential confounder [12];
- effect of mycotoxin exposure on the development and severity of other undernutrition-related diseases such as kwashiorkor and marasmus;
- effect of mycotoxin exposure on the development and severity of diseases related to physical and cognitive development such as neural tube defects, and
- economically feasible and sustainable intervention strategies to reduce exposure.

**Conclusion**

A limited number of epidemiological studies have been conducted on two mycotoxins (AF and FB) with no epidemiological studies investigating DON and ZEA in terms of maternal and IYC exposure and its effect on growth. Strong inverse associations have been found between AF exposure and WAZ, HAZ and WHZ scores and between FB and WAZ and HAZ scores. However, seen in the light of (1) the severe and persistent growth impairment in African countries, (2) the known high levels of these mycotoxins in African staple food, and (3) the strong inverse associations with growth impairment found in animal studies, more epidemiological research is urgently needed to better understand the effect of mycotoxins on growth impairment.

**Disclosure Statement**

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**References**


