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RESEARCH ARTICLE

Risk of zinc deficiency among children aged 0–59 months in sub-Saharan Africa: a narrative review

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Background: Although relatively abundant in nature, zinc deficiency is one of the most prevalent mineral micronutrient deficiencies, particularly in sub-Saharan Africa (SSA). However, there are limited data on zinc nutriture for children in the SSA region.
Objective: A study was undertaken to review the available literature that reported the prevalence of zinc deficiency assessed using the three population-level indicators (plasma/serum zinc, dietary zinc intake and stunting) among children 0–59 months of age in SSA.
Methods: A search combination of words was performed on PUBMED, Google Scholar, AGORA, ScienceDirect and SpringerLink databases. The following search terms were entered; "stunting OR low height for age AND serum zinc OR plasma zinc, AND dietary zinc intake AND under five AND Sub-Saharan Africa".
Results: We identified 25 studies. Two were randomised controlled trials and the rest were cross-sectional studies of which eight were national surveys. Nineteen studies from nine countries have assessed plasma or serum zinc. A total of 10 studies from 6 countries assessed dietary zinc intake. The prevalence of risk of zinc deficiency ranged from 20–83% using PZn/SZn, and 31–99% using inadequate dietary Zn intake, with the exception of one study that reported 8%.
Conclusion: The risk of zinc deficiency among children aged between 0 and 59 months appears to be high and of public health concern. Stunting was the most commonly reported proxy indicator of zinc deficiency. When planning interventions, stakeholders should consider collecting appropriate biomarker data and design context-specific interventions.

Keywords Africa, biomarker, dietary intake, stunting, zinc deficiency

Introduction

Zinc is an essential element required by many human biological processes such as the normal growth and reproduction of all animals, humans and advanced plants[1]. At subcellular level it is vital for the functionality of more than 300 enzymes, and for the stabilization of DNA and gene expression[2]. Zinc is unique in that the body has no specific storage reserves and is hence classified as a Type II nutrient meaning deficiency causes growth retardation as the body tries to conserve the nutrient[3].

Although zinc is relatively abundant in nature, available evidence suggests that its deficiency is one of the most prevalent mineral micronutrient deficiencies worldwide since its first discovery in a young Iranian man in 1961[4]. Because there is no functional reserve or store of available zinc in the human body, except probably in infants[5], a regular, adequate dietary supply is required. Young children, adolescents, and pregnant and lactating women have increased requirements for zinc compared with any other age and sex group and consequently are at increased risk of zinc deficiency[6]. In 2005 an estimated 24% of African children suffered from zinc deficiency[7] and nearly one-third of pre-school-going children in low- and middle-income countries (LMICs) suffer from stunted growth and diarrhoea attributable mostly to zinc deficiency[8]. Zinc deficiency as a risk factor accounts for an estimated 4.8% of all disability adjusted life years (DALYs) among children under 5 years of age in Africa[9].

Although existing research has extensively reviewed zinc nutriture, there is limited information that considers children aged under five years in the sub-Saharan Africa (SSA) region. A few reviews have been undertaken on the zinc status of children; however, these have either included many other target groups, other LMICs or have focused only on plasma or serum zinc status[10,11]. One extensive review has published the stunting prevalence in SSA[12], but none have reviewed and narrated information on the three suggestive indicators of risk of zinc deficiency at the population level, that is, dietary zinc intake, biomarker (serum/plasma zinc levels) and prevalence of stunting[4]. It is recommended that these indicators be applied for national assessments of zinc status to inform interventions. When prevalence of low serum/plasma zinc is greater than 20% in a population, zinc deficiency is of public health concern. Similarly, when prevalence of stunting is 20% or more, the prevalence of zinc deficiency is inferred to be elevated. For dietary indicators, when prevalence of inadequate zinc intake in a population is greater than 25%, the risk of zinc deficiency is considered to be elevated. In the absence of an approved indicator of zinc status and with resources permitting, all the indicators could be used together to obtain the best estimate of the risk of zinc deficiency in a population and to identify subgroups with higher risk of zinc deficiency. In addition, the prevalence of low serum/plasma zinc and inadequate zinc intake may be used to evaluate the impact of interventions on the target population's zinc status[13].

The relatively low number of surveys conducted could be due to the fact that many countries in SSA have not been able to conduct zinc assessments for various reasons such as lack of consensus on inclusion of direct indicators of micronutrients in the health surveys (demographic and health surveys,

micronutrient surveys, national vulnerability assessment survey). This has been compounded by high costs and gaps in research capacity. This review is aimed at providing the available evidence on the prevalence of risk of zinc deficiency using the three suggestive indicators among children 0–60 months of age in SSA.

Methods

Literature search strategy

The Population, Exposure, Comparator and Outcomes (PECO) framework[14] was used as a guideline, where Population referred to children aged 0–59 months in sub-Saharan Africa; in terms of Exposure, in this case there was no exposure and no C-Comparator: and the Outcomes were risk of zinc deficiency assessed using any of the three population-level indicators, i.e. plasma/serum zinc, dietary zinc intake, and stunting prevalence. A search combination of words was performed on PUBMED, Google Scholar, AGORA, ScienceDirect, SpringerLink and Wiley Online databases. The search terms entered were "(stunting OR low height for age) AND serum zinc OR plasma zinc, AND dietary zinc intake AND under five years OR 60 months AND Sub-Saharan Africa AND prevalence". References from the studies identified were also used where possible. The inclusion criteria were as follows: the studies had to be written in the English language and published between 2000 and 2022. For the definition of stunting the studies had to use the World Health Organization (WHO) definition, which is height-for-age (HAZ) or length-for-age (LAZ) less than two standard deviations below the WHO Child Growth Standards median[15]. Low PZn and SZn were defined by cut-offs suggested by International Zinc Nutrition Consultative Group (IZiNCG): < 65 µg dL in the morning, and < 57 µg dL in the afternoon for children below 10 years of age[16]. Inadequate intake was either defined by age and sex-specific cut-off for estimate of average requirements (EARs) of IZiNCG[16] or the EARs derived from the WHO[17] were used: < 4.0 mg/day for children 6–36 months, and < 5.5 mg/day for children 3–8 years. The review included the 46 countries in the SSA region. Single and multi-country studies were included. Any study design was included. It is important to note that this narrative review may not have been entirely exhaustive of all studies available from SSA.

Results and discussion

We identified 25 studies. One was a randomised controlled trial and the rest were cross-sectional studies of which eight were national surveys (Table 1). Stunting was assessed in 36 of the 46 countries in SSA and prevalence of risk of zinc deficiency ranged from 20 to 83% using PZn/SZn, 31–99% using inadequate dietary Zn intake and lastly from 19.1 to 54.6% based on stunting.

Assessment of prevalence of risk of zinc deficiency using plasma and serum zinc

Several studies[18–24] have measured and reported on plasma zinc whilst others[25–33] measured and reported on serum zinc (Table 2). The prevalence of zinc deficiency ranged from 20% to 83%. Besides one study that reported a prevalence of 20%, all countries reported the prevalence of risk of zinc deficiency higher than the 20% cut-off. The risk of zinc deficiency is considered to be elevated if the prevalence of low plasma/serum zinc is greater than 20%[13].

Though different specimens were used for analysis, sufficient evidence shows that when both plasma and serum of samples are retained for identical time periods before separating the cells for analysis, the zinc concentration results do not differ. Hence, PZn concentration and SZn concentration are both considered valid and identical biomarkers of zinc status[1,34]. Standardisation of procedures for the collection of samples for zinc analysis is important in order to compare across surveys[35]. Although all studies used the recommended cut-offs of serum zinc concentration and plasma zinc concentrations in the classification of zinc deficiency[36], one study from Uganda did not control for time of sampling and fasting status, hence they could have underestimated or overestimated the prevalence of zinc deficiency[30]. Plasma zinc concentrations fluctuate by as much as 20% during a 24-hour period, largely due to effects of food ingestion[37]. Following a meal, there is an immediate initial increase, after which the concentration declines progressively for the subsequent four hours then rises until food is eaten again. Falls in plasma zinc concentration of $\leq$ 22% soon after a meal have been reported[37]. During an overnight fast, the concentration of PZn increases slightly, so the highest levels of the day are generally seen in the morning[4,38–40]. Regardless, daytime variations in PZn concentration among fasted individuals have also been observed, where PZn decreased from morning to mid-afternoon and then began to rise again to morning levels[41]. These factors have made it important to control for time of blood collection and fasting status according to published protocol[35].

Assessment of risk of zinc deficiency using prevalence of inadequate dietary intake in SSA

Dietary zinc intake data are a proxy indicator for evaluating the risk of zinc deficiency in populations, with lower levels of dietary zinc intake indicating a higher risk of deficiency. However, availability of complete food composition tables and subsequently comprehensive dietary intake data in most developing countries is very limited[3,42]. A total of 10 studies from 6 countries assessed dietary zinc intake[18–20,27,43–47] (Table 3). Prevalence of inadequate dietary zinc intake ranged from 31% to 99%, with the exception of a study done in Cameroon that reported 8%[18]. Zinc in protein-based foods is found either in its functional form or in intracellular storage forms. These are readily taken up by the body, which makes animal protein-based foods a better source of zinc compared with plant-based foods. Plants are high in phytic acid, which is an inhibitor of zinc bioavailability[48]. Phytate can bind zinc in the intestinal lumen and form an insoluble complex that cannot be digested or absorbed by humans due to lack of the intestinal phytase enzyme[49]. Phytic acid reduces zinc absorption from cereal-based diets to just 30–35% and significantly increases the EAR[50–52]. Diets in SSA are known to be largely cereal-based and monotonous with low animal-source foods. Subsequently they are characterised by inadequate dietary zinc intake. Mean dietary zinc intake among children in SSA ranges from 2 to 8.1 mg/day and is mostly on the low side compared with the EAR for this age group, which is 2.5–4.0 mg/day according to IZiNCG cut-offs (Table 3). Wessells and Brown projected an overall prevalence of inadequate intake of 25.6% for the SSA population based on estimated absorbable zinc supply from food balance sheets[53]. This difference may be attributed to the fact that food balance sheet data are more reflective of adult dietary intakes than intakes of children, as the type of foods consumed and the adequacy of food intakes by young children may differ substantially from those of adults in the same population[4]. The lowest prevalence of inadequate zinc intake of 8% was from a national survey conducted in Cameroon by Engle-Stone et al., which assessed risk of zinc

Table 1: Characteristics of studies from sub-Saharan Africa that assessed prevalence of zinc deficiency among children aged between 0 and 60 months

Country	Ref	Year of study	Age group (months)	*n*	Study design
Benin	[19]	2013	12–60	326	Cross-sectional
				36	Cross sectional
Cameroon	[18]	2014	12–59	1002	National survey
Ethiopia	[28]	2015	6–59	1171	Cross-sectional
	[26]	2011	6–60	240	Cross-sectional
	[25]	2013	6–35	6752	National survey
	[43]	2010	12–23	62BF	Cross-sectional
			12–23	14NBF	
	[44]	2011	6–35	8079	National survey
	[76]	2015	6–59	1143	National survey
Kenya	[45]	2009	24–60	449	Cross-sectional
	[21]	2011–2014	24–72	487	Cross-sectional
	[20]	2014	22–72	184	Randomised Control Trial
	[22]	2014	48–72	112	Cross-sectional
	[32]	2011	6–59	771	National survey
Malawi	[77]	2015–2016	6–59	1086	National Survey
Nigeria	[45]	2009	24–60	793	Cross-sectional
Senegal	[33]	2010	12–59	1151	National Survey
South Africa	[29]	2014	36–60	349	Cross-sectional
	[46]	2011	24–60	128	Cross-sectional
	[47]	2010–2011	24–60	149	Cross-sectional
	[27]	2002	6–12	89	Cross-sectional
	[23]	2005	6–12	194	RCT
	[24]	2007	1–6 years	295	Cross sectional
Uganda	[30]	2005	12–59	247	Cross-sectional baseline survey
Nigeria	[78]	2014	5–60	100	Cross-sectional
Zimbabwe	[79]	2021	5–59	452	Cross-sectional

Notes: *n*: sample size. BF: breastfeeding. NBF: non-breastfeeding.

deficiency by use of all three recommended indicators. The authors explain this low prevalence, which was not consistent with other indicators of nutrient intake they had reported on (PZn, stunting and anaemia), to be attributable to errors in estimating dietary intake such as reporting errors, illiteracy and other methodological errors[18]. They concluded that PZn and stunting prevalence provided strong evidence that zinc deficiency was prevalent among children in the study, even in the presence of apparently adequate total dietary zinc[18].

Diets of countries in the SSA region are predominantly cereal based with low animal-source foods[54]. Literature has shown that zinc deficiency is more prevalent in areas with such dietary patterns and an overall poor dietary intake[16]. The zinc from such diets is poorly absorbed due to the high phytic acid content of plants. Further, children in these SSA countries are frequently affected by enteric infections, which commonly result in excess faecal losses of zinc[55]. Combined, this substantiates a high prevalence of inadequate dietary zinc intake, excessive loss and increased risk of zinc deficiency.

Assessment of risk of zinc deficiency using prevalence of stunting in children under five years of age in SSA

Stunting, defined as low height for age, is the cheapest and easiest indicator to collect in resource-constrained regions. It is estimated that 84 LMICs have a stunting prevalence of greater than 20% among children of less than 5 years old[53]. The downside to using this indicator is the fact that it is a non-specific indicator. Stunting has numerous etiologies[12]. However, due to the role zinc plays in growth and development, stunting is still considered at the population level a proxy indicator of zinc deficiency[56]. More studies seem to have assessed stunting in SSA than any other biomarker, probably due to incorporation of anthropometric data in all national surveys and smaller pilot studies. In a multi-country study by Quamme and Iversen[12], the researchers published the recent prevalence of stunting from 36 of 46 countries in SSA (Table 4). The lowest prevalence was from Senegal (19.1%) and the highest was from Burundi (58.3%). The average prevalence of stunting was 41%. High prevalence of stunting in most countries of SSA can be indicative of zinc deficiency in this region.

Implications for practice

The risk of zinc deficiency among children under five years of age appears to be high and of public health concern in almost all the SSA countries, irrespective of the recommended indicators (proportion below cut-off for plasma zinc concentration, dietary zinc adequacy and stunting prevalence) used. The consequences of zinc deficiency include morbidity from diarrhoea and pneumonia, mortality and stunting in children[57]. These effects often have cross-generational implications as zinc deficiency can affect the growth and development of children, which can have long-term consequences for their health and well-being. For example, stunting due to zinc deficiency has been linked to poor cognitive

Table 2: Studies that assessed plasma zinc and serum zinc levels in children under five years old from countries in sub-Saharan Africa

Country	Ref	Year of study	Age group (months)	*n*	Study design	Zinc deficiency (%)	Biomarker reported
Benin	[19]	2013	12–60	326	Cross-sectional	52.6.	PZn
Cameroon	[18]	2014	12–59	1002	National survey	83.0	PZn
Ethiopia	[28]	2015	6–59	1171	Cross-sectional	24.0	SZn
	[26]	2011	6–60	240	Cross-sectional	57.1	SZn
	[25]	2013	6–35	6752	National survey	79.0	SZn
	[75]	2015	6–59	1143	National survey	35	SZn
Kenya	[32]	2011	6–59	771	National survey	81.6	SZn
	[21]	2011–2014	24–72	487	Cross-sectional	74.4	PZn
	[20]	2014	22–72	184	Randomised Control Trial	42.9–53.3	PZn
	[22]	2014	48–72	112	Cross-sectional	52.0	PZn
Malawi	[77]	2015–2016	6–59	1086	National Survey	60.4	SZn
South Africa	[29]	2014	36–60	349	Cross-sectional	42.6	SZn
South Africa	[27]	2002	6–12	89	Cross-sectional	32–35	SZn
	[23]	2005	6–12		RCT	47	PZn
	[24]	2007	1–3 years	154	Cross-sectional	51.3	PZn
	[24]	2007	4–6 years	141	Cross-sectional	45.4	PZn
Uganda	[30]	2005	12–59 months	247	Cross-sectional baseline survey	54.3	SZn
Nigeria	[80]	2001	< 60 months	2725	National Survey	20	SZn
Nigeria	[78]	2014	5–60 months	100	Cross-sectional	26	SZn
Senegal	[33]	2010	12–59	1151	National Survey	50	SZn

Notes: PZn-plasma zinc, SZn -serum zinc

development, which may result in low quality of life. Additionally, zinc deficiency can increase the risk of morbidity and mortality from diarrhoea and pneumonia, which are leading causes of childhood illness and death in many parts of the world[58]. Children who experience frequent illness and poor health due to zinc deficiency may be less likely to thrive and reach their full potential, which can perpetuate the cycle of poor health across generations[59,60].

Given the magnitude of risk of zinc deficiency in SSA from this review, it is apparent that policy and programming decisions need to be informed by consolidated studies that explore the determinants of zinc deficiency in SSA. Furthermore, this review showed that most countries in SSA have not been able to conduct zinc assessments using direct biomarkers such as plasma/serum zinc concentration; as such, stunting is the most commonly reported proxy indicator of zinc deficiency. The use of various indicators, direct and proxy with different methods of sample collection and laboratory analysis, has made comparison among surveys and studies difficult and in turn masks the true extent of zinc deficiency across SSA. Although newer methods to assess zinc nutrition status such as Linoleic acid:Dihomo-γ-linolenic acid ratio (LA:DGLA)[61] are being proposed, no such studies have been conducted and validated in SSA. Desaturase enzymes require zinc as a cofactor to convert LA to DGLA, hence their activity is very sensitive to early-stage zinc deficiency. The conversion of LA to DGLA is the highest zinc flux pathway, therefore an elevation in the

Table 3: Studies that assessed dietary zinc intake among children from countries in sub-Saharan Africa

Country	Ref	*n*	Dietary assessment method	Zinc	
				mg/day (mean ± SD/median [IQR])	Prevalence of Inadequate intake (%)
Benin	[19]	36	24-hr recall	8.1 ± 2.3	79.5
Cameroon	[18]	108BF	24-hr recall	2.2 ± 0.1	
		667NBF		4.3 ± 0.1	8
Ethiopia	[43]	62BF	24-hr recall	3.3(2.0,4.7)	96
		14NBF		6.7(3.9,8.1)	51
	[44]	8079	24-hr recall	2.0(0.7,3.7)	99
Kenya	[45]	449	24-hr recall	2.8 ± 1.5	99
	[20]	112	24-hr recall	5.8(4,6.6)	85
Nigeria	[45]	793	24-hr recall	3.8 ± 2.9	91
South Africa	[46]	248	FFQ	4.0(2.6,5.6)	90
	[47]	149	24-hr recall	6.2(4.5,9.1)	55
	[27]	62	24-hr recall	4 ± 1	31

Notes: *n*: sample size. BF: breastfeeding. NBF: non-breastfeeding. EAR: estimated average requirement i.e. 2.5–4 mg/day for children 6–59 months. FFQ: food frequency questionnaire

Table 4: Studies that assessed stunting among children below five years from countries in sub-Saharan Africa

Literature reference	Age	Study site and sample	Prevalence of stunting
[40]	1–60 months	33 countries in SSA 368 450	Total: 41.1% Nigeria 39.2% Ethiopia 50.8% DRC 43.4% Highest: Burundi 58.3% Lowest: Gabon 21.0%
[41]	< 60 months	Addis Ababa in Ethiopia 5,822	19.6%
[42]	< 59 months	35 countries 384,747	West 33.9% Central 37.8% East 35.3% South 26.5% Highest: Burundi 54.6% Lowest: Senegal 19.1%
[43]	6–59 months	Wolayta Sodo Town, Ethiopia 315	22.2%
[44]	< 59 months	Nakaseke and Nakasongola districts, Uganda, 104	38.5%
[45]	< 59 months	25 countries in SSA 213,889	49.5% multiple births and 36.9% singleton births
[46]	< 59 months	18 countries in SSA 55,749	
[47]	6–59 months	DRC 3,721	35.2%
[48]	< 59 months	Rwanda 3,594	38%
[49]	< 59 months	Cameroon 5,053 Nigeria 18,823 DRC 3,777	Cameroon 32% Nigeria 41% DRC 44.5%
[50]	6–59 months	Kenya 1,245	47%
[51]	6–59 months	Mozambique 874	37%
[52]	< 59 months	34 countries in SSA 299,065	Highest Burundi 54.6% Lowest in Ghana 19.2%. Highest in Central and East Africa Lowest in the South
[53]	6–59 months	Zimbabwe 452	27.85%

Notes: Reproduced with permission from Quamme and Iversen[12].

LA:DGLA ratio has been proposed to be a very sensitive marker for zinc deficiency[62–64]. Additionally, there is insufficient data on potential biomarkers to establish specific cut-offs for zinc inadequacy in population studies. These potential biomarkers include urinary zinc, hair zinc and neurobehavioral function. Low- and middle-income countries often lack the necessary resources and infrastructure for conducting large-scale studies on zinc deficiency. High research costs and reduced technical capacity hamper progress in this area.

When planning interventions, stakeholders should consider collecting appropriate biomarker data and make use of the recommended population-level indicators. Additionally, as malnutrition is a multifaceted problem, SSA countries are more often tackling food insecurity, which is considered an immediate concern as it addresses the availability of and access to food for individuals and populations. In contrast, micronutrient security is focused on ensuring that individuals received well-balanced diets including sufficient amounts of essential micronutrients, which is often considered a long-term goal. Subsequently, micronutrient deficiencies may not always be the sole focus of targeted research and health interventions in these countries. There is a need for increased awareness and an investment case for prioritizing micronutrient research and alleviation strategies. In view of the evidence summarised in the current review, there is a need for initiatives to support scale-up routine surveillance of risk of zinc deficiency at population level in SSA countries. This will allow planning and implementation of preventive interventions for high-risk populations.

The WHO is yet to established guidelines for large-scale zinc interventions that are designed to prevent inadequate zinc intake and, in turn, poor zinc nutriture. Regardless of publishing guidelines for fortification of maize/corn meal with vitamins and minerals, the WHO reported scarcity of evidence on the effect of fortified maize flour or maize-flour products for zinc on the zinc status and deficiency, growth and adverse effects in children[65]. Lack of a direct relationship between zinc fortification and nutrition outcomes despite improvement in dietary intake has also been reported in studies of South Africa, where prevalence of zinc deficiency among children remained high despite fortification of maize meal and wheat flour with zinc for close to two decades[10,66]. Moreover, in the absence of a gold standard zinc biomarker, programme planners face challenges in assessing and making recommendations for preventive zinc interventions.

Nevertheless, interventions that improve the bioavailability of zinc from plant foods, dietary diversification and increased consumption of animal-source foods have the potential to significantly reduce zinc deficiency in children and women[16]. Industrial zinc fortification and/or biofortification and/or agronomic fortification (zinc fertilizers) are emerging interventions to address zinc deficiency in low-income settings like SSA[67]. However, impact assessment for current zinc fortification programmes in SSA settings is lacking. Additionally, studies that evaluate the effectiveness of zinc supplementation as part of a multiple-micronutrient powder for children and/or pregnant women are warranted[68].

Incorporation of zinc assessment into periodic monitoring and surveillance

Considering the public health relevance of zinc deficiency in most SSA countries, there is a critical need for mainstreaming zinc in routine surveillance frameworks, although there still remains an argument on which biomarker to use and how to address the glaring gap in availability of biomarker data from SSA. Nonetheless, the determination of zinc deficiency is mandatory for the design of evidence-based strategies for its alleviation. Therefore, following determination of groups at high risk of zinc deficiency, the choice of intervention will be determined by the urgency of the situation, resources available, technology required to deliver and sustain the interventions and evidence in support of the intervention type[16]. Additionally, complementary interventions should be combined with ongoing national food, nutrition and health programmes, and promoted by mainstreaming them into existing nutrition education and social marketing techniques to improve their effectiveness and

sustainability. A multi-sectorial approach involving various sectors such as government, public health, industry and education is also needed for the success of routine surveillance and intervention rollout.

Soil health, agronomic fortification and zinc deficiency

Zinc deficiency in soils is an important constraint to crop production, and the most ubiquitous micronutrient deficient in crops worldwide,[69] particularly limiting yields in SSA[70]. In settings where soils and crops are deficient in zinc, there is a correlation between low soil zinc and lower plasma/serum zinc as well as low weight-for-height among children[28]. Therefore, in SSA where zinc deficiency is widespread, the use of agronomic fortification and fortification for maize has the potential to address this public health problem if mainstreamed within the framework of existing interventions. Biofortification is a process of enhancing the content of vitamins and minerals in a crop through plant breeding, transgenic techniques or agronomic practices[71]. Biofortified staple crops, when consumed regularly, will generate measurable improvements in human health and nutrition[72–74]. Agronomic biofortification is the addition of limited micronutrients to several crops through ground fertilisers or foliar application to improve soil zinc or plant zinc content respectively[71]. For agronomic biofortification to be successful, there must be a causal link between soil Zn and human Zn status in target communities in targeted geographical spaces[75]. Therefore, studies that explore this critical link in SSA countries are required to inform policy direction.

Conclusions and recommendations

In conclusion, the available data indicate that the prevalence of zinc deficiency among children under five years of age in SSA countries is elevated and of public health concern. Many countries in SSA have not been able to conduct zinc assessments using recommended biomarkers and, as such, stunting is the most commonly reported proxy indicator of zinc deficiency. Therefore, when planning interventions targeted at alleviating zinc deficiency, stakeholders and policy-makers should invest in assessing the recommended biomarkers of zinc status. They should take into consideration the demographic, socioeconomic, geographical and pathological factors shown to be associated with the risk of zinc deficiency in children from African countries, to design context-specific interventions. Specifically, the improvement of zinc bioavailability in plant foods as well as the potential of the application of biofortification and agronomic biofortification in addressing zinc deficiency in SSA has been documented and can be considered during intervention design.

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