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Micronutrient Deficiencies and Food Fortification Policies in Sub-Saharan Africa: A Document Review of Effectiveness, Equity, and Future Directions

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Abstract: Micronutrient deficiencies (MNDs)—including iron-deficiency anemia, vitamin A deficiency, iodine deficiency and zinc deficiency—continue to be a complex problem in Sub-Saharan Africa (SSA) that disproportionately burdens women of childbearing age, infants and young children, as well as other vulnerable populations. The following three consumer staples—universal salt iodization (USI), flour fortification, and edible oil fortification—and large-scale food fortification (LSFF) have been recognized as cost-effective interventions. Despite such efforts however, progress has been uneven, with gaps and weak enforcement of legal instruments, poor monitoring systems, unequal coverage and donor dependency in financing minimizing the impact. There is progress, for example decreases in neural tube defects in South Africa and improved iodine sufficiency in certain countries, but wider reductions in anemia and vitamin A deficiency remain erratic. There is a strong equity dimension involved, notably because urban and wealthy groups benefit more than rural and marginalized ones. New solutions — biofortification of staple crops, digital surveillance platforms and enhanced public--private collaborations -- hold the potential to address these gaps, but their long-term sustainability and integration with other nutrition strategies need to be investigated. This scoping review assesses the evidence on the applicability, effective coverage and policy implications of fortification in SSA while highlighting best practices for success, ongoing challenges and research priorities to guide future nutrition policy and programming.

Keywords: *Micronutrient Deficiencies; Food Fortification; Equity; Sub-Saharan Africa; Anemia; Biofortification; Nutrition Policy; Public–Private Partnerships.*

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I. INTRODUCTION

Micronutrient deficiencies (MNDs) continue to be a major public health problem in Sub-Saharan Africa (SSA) and iron-deficiency anemia (IDA), vitamin A deficiency (VAD), iodine deficiency (ID), and zinc deficiency (ZnD) are associated with significant morbidity and mortality throughout the life span [1–3]. Anemia globally in 2019 was estimated to have affected approximately 30% of non-pregnant and 37% of pregnant women aged 15–49 years, with the greatest burden localized in areas such as SSA where dietary iron intakes and bioavailability is generally poor, and where infection/inflammation burdens are high [1,4,5]. VAD is also endemic to SSA: VAD was listed as a public-health significance in 2013, with prevalence rates for about one third of children aged 6–59 months and the prevalence mass being concentrated in SSA (48% only) [6,7]. There is considerable improvement in iodine status in several countries with universal salt iodization (USI), but coverage and adequacy are variable, and regular surveillance is necessary to avoid re-emergence [8–10]. Zinc Deficiency Zinc deficiency is also a public health concern because of cereal-based diets rich in phytate, which inhibit absorption; it has been estimated that ~17% of the world's population is at risk with SSA being

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among the worst affected regions [11–14]. Table 1 provides an overview of the main impacts and consequences of these deficiencies.

The effects of MNDs are deep and multi-generational. IDA raises the danger for poor pregnancy and birth outcomes, maternal death, and hindered work productivity; in children anemia and iron deficiency correlate with diminished cognitive as well as motor development [1,4]. VAD is still one of the most significant causes of preventable childhood blindness and increases infection related-mortality [7]. Maternal iodine deficiency leads to decreased infant brain development, subsequently reducing general population IQ and human capital [8–10]. ZnD impairs immune response, increases the risk of infection, and is associated with growth retardation [12–14]. When used with the right vehicle selection, standards, and quality assurance, large-scale food fortification (LSFF) is one of the most economical and scalable methods to lower MNDs [15–18]. Since USI has been a historic success in many contexts, many SSA countries require that wheat flour be fortified with iron and folic acid, and that edible oils and sugar be fortified with vitamin A. In countries where maize is the staple grain, maize flour fortification is becoming more and more common [16,18]. The primary fortification vehicles and the policy environment in SSA are described in Table 2.

Notwithstanding this widespread adoption, little is known about implementation flaws, injustices, and sustainability issues. While rural households that depend on informal markets or small-scale milling are less likely to benefit, coverage frequently favors urban and wealthier populations that consume industrially processed foods [3–5]. Program quality is also compromised by inconsistent standard compliance, lax enforcement, and a lack of regulatory authority [6,7].

Thus, the justification for this review is straightforward: despite the fact that fortification programs have been in place in SSA for many years, there is still conflicting data regarding their long-term efficacy, quality control, and equitable coverage [4,6,8]. National surveillance data is inconsistent, and the majority of evaluations concentrate on inputs or modeled impacts rather than biological or health outcomes. Policymakers' capacity to improve standards, fortify regulatory frameworks, and guarantee that fortification provides equitable and long-lasting public health benefits in a variety of African contexts is hampered by these gaps [5–8].

Table 1 Shows the Prevalence of Micronutrient Deficiencies and their Effects in SSA.

Nutrient	Indicative burden in SSA	Key health consequences
Iron (anemia)	Anemia is one of the most common conditions in the world, affecting about 30% of non-pregnant women and 37% of pregnant women, with SSA accounting for a significant portion of these cases [1,4,5].	Reduced productivity, poor pregnancy and delivery outcomes, impaired cognitive development, and maternal mortality [1,4].
Vitamin A	In 2013, approximately one in three children aged 6 to 59 months had VAD; the highest prevalence was found in SSA (~48%) [6,7].	increased infection severity and mortality, blindness, corneal damage, and night blindness [7].
Iodine	Although USI improved many SSA countries, coverage and adequacy vary, and small-scale producers present risks [8–10].	reduced IQ, goiter, hypothyroidism, and impaired fetal brain development [8–10].
Zinc	Cereal-based, high-phytate diets increase risk; SSA is one of the highest-risk areas [11–14].	Stunting/growth faltering; infection risk; weakened immunity [12–14].

Table 2 Common Fortification Vehicles and Policy Landscape in SSA

Nutrient	Typical vehicle(s)	Policy status & coverage considerations
Iodine	Industrial and household salt (USI)	Broadly mandated; inconsistent coverage; gaps in enforcement with regard to small producers [8–10,17].
Iron (± folic acid)	Wheat flour, maize flour	Common mandates; bioavailability is dependent on the fortifier used; maize is fortified where it is a staple [16,18].
Vitamin A	Edible oils, sugar, wheat/maize flour	Mandates expanding; effectiveness depends on vehicle coverage and informal market penetration [16,18].
Zinc	Wheat/maize flour (co-fortification)	Increasingly included in flour standards; modeling suggests large reductions in inadequacy [14,18].

➢ *Research Questions*

- What is the present burden and pattern of essential micronutrient deficiencies (iron, vitamin A, iodine, zinc) in SSA populations?
- To what extent have food fortification policies at present in place (NaCl, flour and edible oil) contributed to the improvement of population micronutrient status?
- Who gains most from fortification programmes and who can be said to be "left behind" (groups such as those that are poor, rural, refugee-affected or living with HIV)?
- What obstacles impede fortification programming in SSA from being enforced, adhered to and sustained?
- What is the future of micronutrient interventions, with new approaches such as biofortification, digital monitoring tools and public–private partnerships?

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- What are the important research gaps in assessing the long-term health effects, equity, and harmonization of fortification with other nutrition interventions?

➢ *Objectives of the Document Review*

- To produce evidence on the burden and impact of six major micronutrient deficiencies in SSA.
- To estimate the coverage and impact of fortification programmes, including salt iodisation, flour and oil fortification.
- To explore issues of equity and coverage, who stands to gain most, and who is left out.
- To review the problems and barriers to compliance, enforcement, and monitoring of fortification legislation.
- To assess new and upcoming technologies—biofortification, digital solutions, and collaborations—and their promise for nutrition programs.
- To map major research gaps and suggest directions towards more sustainable, equitable and integrated fortification programmes.

II. METHODOLOGICAL APPROACH

Sources: peer-reviewed journal articles, WHO/UNICEF/FAO reports, Demographic and Health Surveys (DHS), Global Fortification Data Exchange, and national policy documents. Inclusion: Studies and reports published in the last 15–20 years (2005–2025). Analysis: Thematic synthesis focusing on types of fortification, implementation strategies, coverage, outcomes, and equity.

III. THEMATIC REVIEW OUTLINE

➢ *Burden of Micronutrient Deficiencies*

Iron-deficiency anemia (IDA), vitamin A deficiency (VAD), iodine deficiency (ID), and zinc deficiency (ZnD) are the leading causes of morbidity and mortality in Sub-Saharan Africa (SSA), where micronutrient deficiencies are still pervasive [19–21]. Worldwide, anemia impacted SSA contributed disproportionately because of high infection burdens and dietary restrictions, accounting for about 30% of non-pregnant women and 37% of pregnant women in 2019 [19,22,23]. In certain SSA nations, the prevalence of anemia in children under five surpasses 60% [24].

According to estimates from the World Health Organization (WHO), 48% of children in SSA between the ages of 6 and 59 months suffered from vitamin A deficiency in 2013 [25]. VAD is still a serious public health concern. UNICEF and National Demographic and Health Surveys (DHS) data confirm the high prevalence among pregnant women and young children, even with improvements inplementation and fortification initiatives [26].

Iodine deficiency has declined globally following the expansion of universal salt iodization (USI), but regional disparities persist. While countries such as Ghana, Kenya, and Tanzania report household coverage above 80%, others (e.g., Niger, Madagascar, Democratic Republic of Congostill exhibit insufficient iodine intake, primarily as a result of lax enforcement of regulations and dependence on small-scale salt producers [27,28]. Although ZnD is not as widely measured as it is in SSA, dietary modeling estimates suggest that up to 25–30% of the population may be at risk of inadequate intake, primarily due to the high phytate content and low animal-source food content of cereal-based diets [29–31].

➢ *Groups Most Affected*

The following bear the greatest burden of MNDs:

- Children under five are particularly susceptible to developmental delays caused by anemia, stunting caused by ZnD, and blindness caused by VAD [25, 29].
- Due to their fast growth, menstrual blood loss (in girls), and poor diet, adolescents are frequently disregarded but are at risk for anemia and iron deficiency [22, 24].
- Women who are pregnant or nursing are disproportionately impacted by anemia and VAD, which can have a direct impact on birth outcomes and maternal mortality [19,26].
- Micronutrient deficiencies are more noticeable in HIV/AIDS-affected populations because of increased metabolic demands, nutrient malabsorption, and chronic inflammation [32].

➢ *Regional Patterns*

There is noticeable regional variation in the burden of deficiencies throughout SSA:

- West Africa: Persistent VAD, patchy salt iodization compliance, and high prevalence of anemia among reproductive-age women (>50% in Nigeria, Mali, and Sierra Leone) [23,27].
- East Africa: Although there has been some progress in fortification (for example, Kenya has made it mandatory for maize and wheat flour to be fortified), anemia and zinc deficiency are still very common; in many nations, stunting rates are higher than 30% [24, 28].
- Southern Africa: More fortification policies are being implemented (such as the country's comprehensive wheat and maize flour program), but disparities between urban and rural populations still exist, and obesity and micronutrient deficiencies are starting to coexist [30, 33].

Table 3 Anemia, VAD, ID, and ZnD Prevalence in SSA by Subregion (West, East, and Southern Africa) is Shown in

Deficiency	West Africa	East Africa	Southern Africa
WRA 15-49 years of anemia	50-60% [19,23]	35-45% [19,24]	30-35% [19,24]
Deficiency in Vitamin A (U5)	40-50% [25,26]	35-45% [25,26]	20-30% [25,26]
Deficiency in Iodine (insufficient iodization of salt)	20-40% [27,28]	15-25% [27,28]	10-20% [27,28]
Zinc Deficiency Risk	25-30% [29,30]	20-25% [29,30]	15-20% [29,31]

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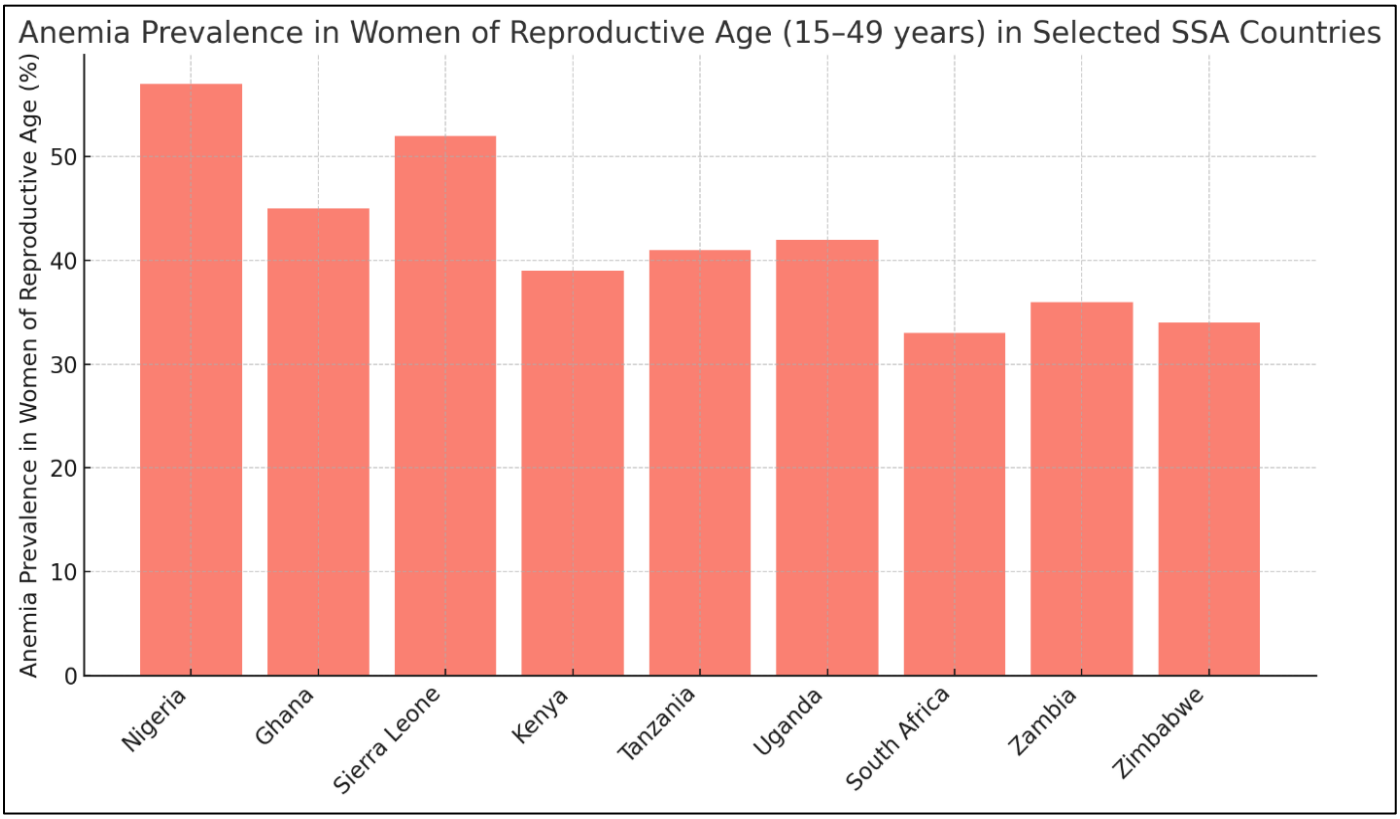

Fig 1 Shows the Prevalence of Anemia in a Subset of Sub-Saharan African Nations Among Women Aged 15 to 49. Sources: WHO Global Health Observatory [19,20], World Bank Data [23], UNICEF (2025) [24].

IV. AFRICAN FOOD FORTIFICATION POLICIES

➢ *An Outline of the Main Fortification Initiatives*

Iodization of salt (USI). Although universal salt iodization is practically universal in Africa, there is still considerable variation in compliance and adequacy, particularly among informal markets and small-scale producers [34, 35]. Fortification of flour with iron, folic acid, zinc, and B vitamins. Throughout SSA, wheat (and in certain countries, maize) flour is frequently required to be fortified. However, the type of fortifier used, industrial milling coverage, and regulatory monitoring all affect the program's impact. Outside of salt, there are still data gaps [34, 36]. Vitamin A fortification of edible oils. The effectiveness of vitamin A fortification of edible oils and fats in many African countries depends on the market share of industrial oils relative to unbranded or informal-sector oils [34].

➢ *Case Studies by Country*

- *Nigeria*

Nigeria has long required salt iodization, oil fortification with vitamin A, and flour fortification with iron, folic acid, zinc, B vitamins, and vitamin A. The legal framework was reinforced by NAFDAC regulations in 2019 and 2021. Compliance monitoring, however, shows differences amongst industry participants [37–39].

- *Ghana*

Ghana requires wheat flour to be fortified with iron, zinc, folate, B vitamins, and vitamin A, and edible oils to be fortified with vitamin A. Despite the existence of standards, national reviews reveal difficulties in meeting the target nutrient levels [40, 41].

- *South Africa*

The program in South Africa is one of the best in the continent. Fortification of wheat flour and maize meal with a multi-micronutrient premix (vitamin A, iron, zinc, folic acid, and B-vitamins) has been required since Regulation R.504 (2003). Comprehensive QA/QC guidelines support implementation [42–44].

- *Kenya*

Kenya needs to fortify edible oils with vitamin A and packaged wheat and maize flour with iron, zinc, folic acid, B vitamins, and vitamin A. The program was formally established by the Kenya National Food Fortification Strategic Plan (2018–2022). Nonetheless, research indicates discrepancies in compliance among smaller mills [45–47].

- *Ethiopia*

Ethiopia has approved fortifying edible oils with vitamin A and wheat flour with several micronutrients, and it enforces mandatory salt iodization. The government and partners support the nationwide rollout. In certain sectors, compliance is voluntary, and implementation is still in its early stages [48, 49].

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Table 4 Overview of Fortification Requirements and Conditions in a Few SSA Nations

Country	Legal basis / update	Vehicles	Nutrients	Implementation notes
Nigeria	Regulations of NAFDAC (2019, 2021) [37, 38]	Salt; edible oils; and wheat or maize flour	Iodine, vitamin A, zinc, folate, and B vitamins	Long-standing regulations; inconsistent compliance; gaps in QA/QC [39]
Ghana	Guidelines for Trade and the Ghana Standards Authority [40, 41]	Salt, edible oils, and wheat flour	Iodine, vitamin A, zinc, folate, and B vitamins	Nutrient levels below standards; mandatory, but inconsistent compliance [40,41]
South Africa	[42] Regulation R.504 (2003)	Maize and wheat flour; salt	Folic acid, vitamin A, zinc, iron, and B vitamins; iodine	Robust legal foundation; codified QA/QC; difficulties reaching rural areas [43,44]
Kenya	Strategic Plan for National Fortification (2018) [45]	Salt; edible oils; and wheat and maize flour	Iodine, vitamin A, zinc, folate, and B vitamins	Packaged goods must comply; small mills have compliance gaps [46, 47].
Ethiopia	Support from the National Standards Council [48,49]	Wheat flour, edible oils, and salt are required (rolling out/endorsed).	Iodine, vitamin A, iron, zinc, and folate	Ongoing is the shift from endorsement to full nationwide rollout [48,49].

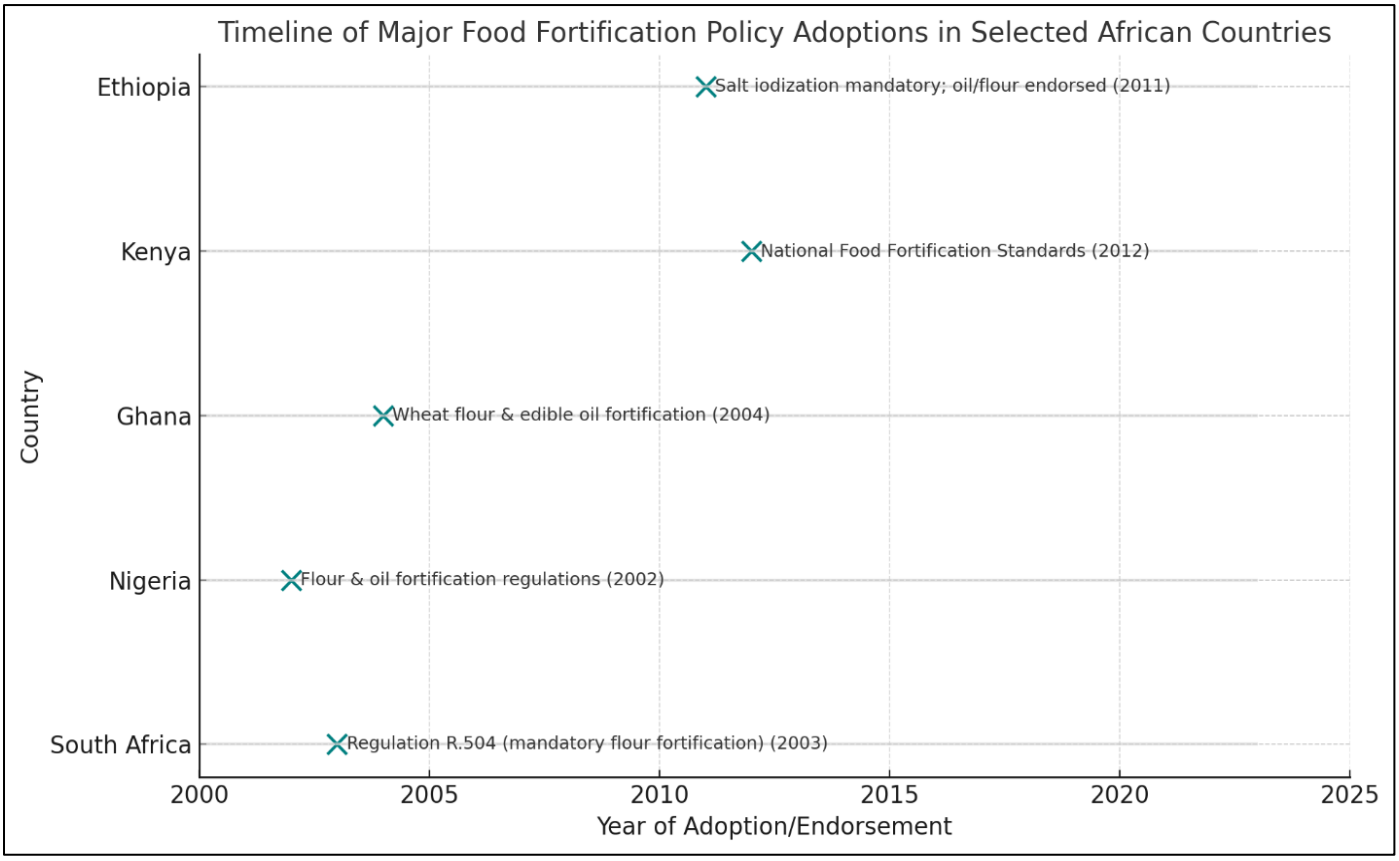

Fig 2 Timeline of major food fortification policy adoptions in selected Sub-Saharan African countries. Sources: South Africa Regulation R.504 (2003) [42]; Nigeria NAFDAC regulations (2002–2021) [37–39]; Ghana Standards Authority & FAIRS reports (2004 onward) [40,41]; Kenya National Fortification Standards & Strategic Plan (2012, 2018) [45]; Ethiopia EPHI and Nutrition International briefs (2011 onward) [48,49].

V. EFFECTIVENESS AND OUTCOMES

➢ *Proof of Influence*

Micronutrient deficiencies have decreased in a number of African nations as a result of large-scale food fortification (LSFF), though results differ depending on the nutrient, context, and monitoring system.

- Reduction of anemia. There is conflicting evidence regarding quantifiable decreases in anemia caused by flour fortification. Iron status has improved in several nations, according to a global systematic review, but the decrease in anemia is not always substantial, in part because it can have multiple causes, including infection, malaria, and inflammation [50]. Iron and folate fortification of flour was associated with fewer neural tube defects in South Africa, although the results for anemia outcomes in women were less clear [51,52].
- Status of vitamin A. In Ghana, mandatory vitamin A fortification of sugar and edible oil has been linked to

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higher serum retinol levels and better vitamin A intake. Nigeria, as as well as Tanzania, particularly in urban areas where industrially refined oil is consumed [53,54]. Impact is limited in rural areas, though, because households frequently use unfortified local oil [55].

- Iodine sufficiency is a big deal. Universal salt iodization has turned out to be one of the most effective fortification initiatives out there. In many countries across Sub-Saharan Africa, household coverage has surpassed 80%, leading to noticeable drops in goiter cases and better median urinary iodine concentration (UIC) levels, especially in places like Ghana, Kenya, and Tanzania. However, there are still some communities at risk, particularly where small-scale salt producers are the norm.
- Zinc results. There are currently few direct biological outcome data available, but modeling studies indicate that depending on standards and coverage, zinc fortification of flour could lower the prevalence of inadequate intake by 20–50% [59].

➢ *Variability in Different Contexts*

Effectiveness varies by region and socioeconomic group.

- Urban versus rural: Urban households exhibit greater improvements in nutrient intake because they are more likely to buy industrially processed fortified foods (flour, oil, and iodized salt). On the other hand, fortified products are frequently unavailable to rural households that depend on small mills and local markets [55,58,60].
- Socioeconomic status: Because they can afford packaged and industrially fortified foods, wealthier households typically benefit more, underscoring the issues of equity in fortification programs [60,61].

➢ *Limited Impact vs. Success Stories*

- South Africa (success story): A significant public health achievement, the implementation of mandatory flour fortification in 2003 (vitamin A, folic acid, iron, zinc, and B-vitamins) was linked to a 30% decrease in neural tube defects within six years [51,52].
- Ghana and Nigeria (mixed results): Although both nations have extensive laws, inconsistent adherence has prevented consistent biological results. Research indicates that vitamin A fortification works well in urban oil markets, but the results for anemia and folate are delayed because of issues with bioavailability and enforcement [54,61].
- Ethiopia (limited impact to date): There is currently little direct biological outcome evidence despite policy endorsements due to implementation gaps and the limited rollout of oil and wheat fortification [62].

Table 5 Selected Data Regarding the Efficacy of SSA's Fortification Initiatives

Country	Vehicle & Nutrient	Documented Outcomes	Notes
South Africa	Flour made from wheat and maize (Fe, folic acid, vitamin A, zinc, and B vitamins)	After required fortification, neural tube defects decreased by about 30% [51,52].	SSA has one of the strongest evidence bases; the impact of anemia is less clear.
Nigeria	Edible oil (vitamin A); wheat flour (folic acid, zinc, iron, and vitamin A)	Improved vitamin A intake in urban oil consumers, with limited anemia reduction [54,61].	Variability in compliance amongst mills; iron compound bioavailability is a problem
Ghana	Wheat flour containing vitamin A, zinc, folate, and B vitamins; edible oil containing vitamin A	Urban populations' increased consumption of vitamin A [53,54]	Lower access in rural areas; difficulties with enforcement
Kenya	Multi-micronutrient edible oils and wheat/maize flour	Although vitamin A intake has improved, anemia rates are still high, according to a national survey [55,58].	Gaps in coverage for the rural milling industry
Tanzania	Edible oil (vitamin A) and salt (iodine)	Reduced prevalence of goiter; median UIC within sufficiency range [56]	USI program is strong, but there is some small-scale salt leakage.
Ethiopia	Salt (wheat or oil recommended; iodine required)	In certain areas, salt iodization increased UIC [62]; oil and flour had little effect.	Phase of scale-up, limited data from biological monitoring

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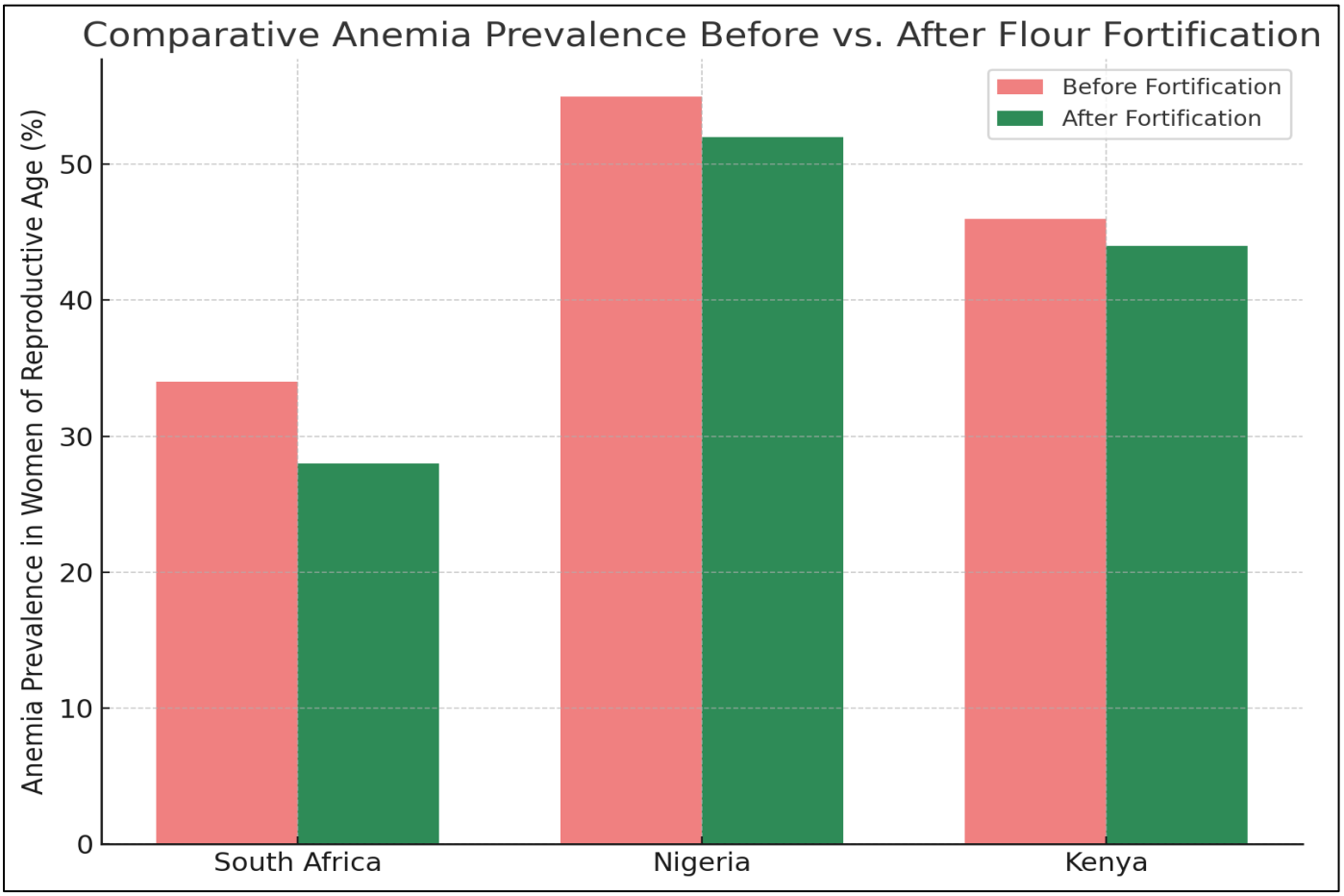

Fig 3 Prevalence of anemia in women aged 15–49 years prior to and following flour fortification in a few Sub-Saharan African nations. Sources: Pachón et al. (2015) [50]; Sayed et al. (2008) [51]; Khamila et al. (2020) [55]; GAIN (2022) [61]. This graphic shows that although some nations (Kenya, Nigeria) have seen only slight decreases, South Africa has seen quantifiable drops, primarily as a result of strict laws, strict enforcement, and premix design.

VI. DIFFICULTIES AND OBSTACLES

In Sub-Saharan Africa, a number of obstacles still restrict the efficacy and sustainability of fortification mandates, even though they have been widely adopted.

➢ *Inadequate Regulatory and Enforcement Mechanisms*

Because of weak penalties for non-compliance, fragmented institutional roles, and limited regulatory capacity, enforcement of fortification laws is inconsistent in many countries [63,64]. As a result, fortified foods frequently fall short of market-level requirements [65].

➢ *Industry Compliance and Exclusion of Small-Scale Millers*

Fortification standards are more likely to be followed by large industrial producers, but small and medium-sized millers, who control rural food supply chains, frequently lack the technical know-how, tools, and incentives to fortify [66,67]. Consequently, fortified foods are less accessible to rural populations that rely on small mills [68].

➢ *Cost and Buyer Reach*

Although fortification is considered cost-effective at the population level, fortified products may remain less affordable for low-income households when price differentials exist. Because informal or unfortified substitutes are frequently less expensive, equitable access is compromised [69, 70].

➢ *Gaps in Assessment and Quality Control (QA/QC)*

With limited laboratory capacity, inadequate testing, and disjointed information systems, routine monitoring of fortified products is frequently restricted or donor-dependent [64,71]. Fortified foods are hard to ensure meet nutrient requirements without strong QA/QC systems.

➢ *Inadequate Coordination with Additional Nutrition-Related Interventions*

Instead of being combined with complementary interventions like supplementation, dietary diversification, and public health initiatives, fortification programs are commonly carried out in isolation. Their ability to work in concert to lessen micronutrient deficiencies is thus compromised [68,72].

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Table 6 Major Obstacles and Difficulties in SSA's Food Fortification Initiatives

Barrier	Description	Example country contexts	Sources
Poor enforcement	Insufficient regulatory monitoring and insufficient sanctions for non-adherence	Ethiopia has poor rollout enforcement [71]; Nigeria has inconsistent compliance despite regulations [63, 65].	[63–65,71]
Excluded are small-scale millers.	Inadequate fortification incentives, equipment, or capacity	Ghana: rural households rely on non-fortified flour [67]; Kenya: small mills avoid fortification [66,68].	[66–68]
Accessibility and affordability	Better products cost more, but unreliable, less expensive alternatives are frequently available.	Tanzania's rural poor have less access to fortified oil [69], while Nigeria's informal flour and oil markets are more prevalent [70].	[69,70]
QA/QC gaps	Lab capacity limitations and inadequate routine monitoring	Weak QC systems during rollout in Ethiopia [71]; donor-dependent lab testing in the region [64]	[64,71]
Inadequate integration	Programs unrelated to diet diversification or supplements	Malawi: fortification is unrelated to nutrition or child health initiatives [72].	[72]

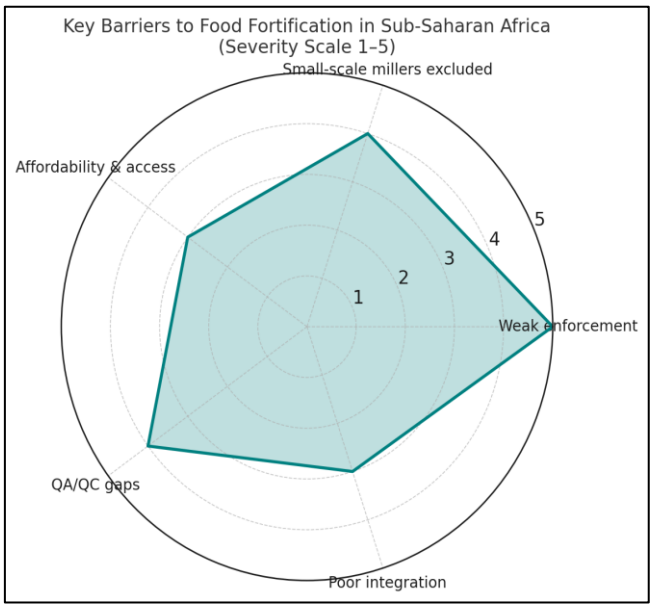

Fig 4 Perceived Severity of Barriers to Food Fortification Programs in Sub-Saharan Africa.
Sources: Mkambula et al. (2020) [63]; Luthringer et al. (2015) [64]; GAIN (2022) [65]; Osendarp et al. (2021) [67].

VII. COVERAGE AND EQUITY

➢ *A Who Gains the Most, and who Loses Out?*

While rural and poorer households that depend on small-scale mills or informal markets are less likely to consume appropriately fortified products, urban and higher-income households that buy industrially processed foods benefit disproportionately from fortification programs [73–75]. Urban areas consume more fortified flour and oil than rural ones, according to national coverage surveys, especially in nations where informal milling is prevalent [76].

➢ *Disparities in Socioeconomic Status and Gender*

Although the intended primary beneficiaries of fortification are women of reproductive age and children under five, the benefits are not evenly distributed. For instance, compared to rural and poorer quintiles, urban wealthier quintiles in Nigeria and Ghana report consuming substantially more fortified flour and oil [74,77]. Gender disparities are also evident: compared to wealthier, more educated women, women with lower incomes or levels of education frequently have less access to fortified products [78].

➢ *Urban-Rural Divide*

Research continuously demonstrates that urban households gain more because packaged, fortified products are more easily accessible [75,79]. People living in rural areas, particularly in East and West Africa, frequently eat oil from unofficial processors and flour from nearby hammer mills, which are rarely fortified [76,79]. This gap between rural and urban areas jeopardizes equity objectives.

➢ *Marginalized Groups*

- Refugees and internally displaced people (IDPs): Food assistance programs occasionally provide fortified goods, but coverage is contingent on logistics and donor funding [80].
- Targeted inclusion in fortification programs is uncommon for HIV-affected populations, despite their high susceptibility to micronutrient deficiencies; instead of benefiting from fortified foods, these groups frequently rely on supplements [81].
- Informal-sector consumers: Regular consumption of fortified foods is less common among populations that rely on unregulated markets (street foods, unbranded oils, small mills) [74,76].

Table 7 Patterns of Equity and Coverage in SSA's Food Fortification Initiatives

Dimension	Beneficiaries	Left behind	Examples	Sources
Geographic (Urban vs. Rural)	Access to industrial food supply chains by urban populations	Rural households that depend on local oil and small-scale mills	Urban oil and flour in Nigeria and Kenya are more robust than their rural counterparts.	[74–76,79]
Socio-economic status	Richer households buying packaged foods	Poorer households purchasing less expensive, unfortified alternatives	The richest quintile consumes the most fortified oil and flour in Ghana and Nigeria.	[74,77]

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Gender	Educated women with greater purchasing power.	Women of reproductive age with low incomes, particularly in rural areas	Surveys reveal differences in the consumption of fortified oil by income and education.	[78]
Marginalized groups	IDPs and refugees in camps receiving fortified food assistance	HIV-affected populations, refugees in host communities, and internally displaced people outside of camps	WFP initiatives in South Sudan and Ethiopia; HIV+ women depend on supplements rather than fortification	[80,81]

VIII. NEW CONCERNS AND DEVELOPMENTS

➢ *Biofortification*

Breeding staple crops with a higher micronutrient content, or biofortification, has become a promising addition to large-scale food fortification in recent years. Vitamin A-enriched maize and orange-fleshed sweet potatoes (OFSP) are two examples from Sub-Saharan Africa that have been shown to improve children's serum retinol status [82,83]. Similar to this, HarvestPlus and national agricultural initiatives have aided in the adoption of iron-rich beans and zinc-rich wheat in East and Southern Africa [84]. Biofortification addresses equity gaps by reaching rural smallholder populations that consume subsistence crops, in contrast to industrial fortification [85].

➢ *Digital Monitoring Tools and Public–Private Partnerships*

Inadequate regulatory monitoring is still an enduring challenge, but there are experiments with digital instruments as ways to enhance monitoring. There is, for example, the application of FortifyMIS (Fortification Monitoring Information System) in Nigeria, with which the regulator is able to monitor compliance with fortification in real-time [86]. Public–private partnerships (PPPs) between governments, industry, and NGOs (such as GAIN, Nutrition International) are also becoming an integral factor in enhancing supply chains, QA/QC systems, and awareness among consumers [87].

➢ *Cost-Effectiveness and Sustainability Debates*

With estimated returns on investment ranging from US$8 to US$84 for every US$1 spent, food fortification remains one of the most economical nutrition interventions [88]. Nonetheless, questions remain regarding the viability of donor-driven initiatives and whether governments can continue to provide subsidies, monitoring, and fortification infrastructure after external funding declines [89]. Furthermore, discussions center on striking a balance between fortification and complementary tactics like supplementation and dietary diversification [90].

Table 8 New Developments and Concerns in SSA's Micronutrient Interventions

Innovation	Examples in SSA	Key Benefits	Challenges	Sources
Biofortification	OFSP (Mozambique, Malawi), iron beans (Rwanda, Uganda), and vitamin A maize (Zambia, Nigeria)	enhances iron and vitamin A status and reaches rural impoverished people who depend on subsistence farming [82–85].	Consumer preferences, seed systems, and farmer acceptance all affect adoption rates [84,85].	[82–85]
Digital monitoring tools	SMS-based fortification tracking pilots and FortifyMIS (Nigeria)	improves regulatory enforcement, transparency, and real-time monitoring [86]	requires training and digital infrastructure; adoption is uneven.	[86]
Public–private partnerships	Nutrition International, HarvestPlus, and GAIN with national governments	Increase capacity, enhance QA/QC, and guarantee supply of premix and increase consumer awareness [87]	dependence on donations; risks to sustainability	[87]
Cost-effectiveness	Return on investment (ROI) research in LMICs; South African and Nigerian SSA case studies	Outstanding return on investment (US$8–84 for every $1 spent); DALYs are prevented [88].	Government support and sustained funding are crucial [88–90].	[88–89]

IX. EVALUATION SHORTCOMINGS DISCOVERED

➢ *Despite Lengthy Evaluations of Fortification Impact*

Long-term population-level outcomes, such as sustained reductions in anemia or decreases in child stunting, are still not well documented, despite short-term evaluations demonstrating improvements in micronutrient intake [91,92]. The majority of studies evaluate coverage and compliance, according to systematic reviews, but few monitor health outcomes over a number of years [93].

➢ *Lacking Proof for Equality*

The aspects of equity—who gains the most and who loses out—are not sufficiently studied. Despite evidence of differences in access to fortified foods, there are few disaggregated analyses by gender, wealth quintile, and rural-urban location [94,95]. It is challenging to customize fortification programs for underserved populations due to the dearth of reliable equity data.

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➢ *Inadequate Sustainability and Funding Model Documentation*

A large portion of SSA's fortification infrastructure is dependent on donor funding for monitoring, lab equipment, and premix acquisition. However, there is little research on private-sector cost-sharing, domestic resource mobilization, and sustainable financing models [96,97]. Without this, when donor funding declines, long-term continuity is uncertain.

➢ *Integration with Other Interventions is Not Sufficiently Explored*

Frequently, fortification is used as an independent intervention. There is little data on the interactions between fortification, dietary diversification, supplementation, and infection control strategies [92,98]. Impact could be maximized by integrated program designs, but synergy documentation is still lacking.

Table 9 An Overview of the Research Gaps in SSA's Fortification Programs

Research gap	Current status	Implication	Sources
Long-term evaluations	Few national or longitudinal outcome studies; inputs and coverage are the main focus.	It's unclear if fortification can scale up and sustainably lower anemia, VAD, and ZnD.	[91–93]
Equity analyses	Limited data broken down by wealth, gender, and rural-urban	Underserved vulnerable groups might continue to exist.	[94,95]
Sustainability & funding	Programs primarily rely on donors; little is known about domestic financing models.	Collapse risk in the absence of outside assistance	[96,97]
Combining other nutrition-related interventions	Seldom assessed in conjunction with dietary diversification and supplements	Missed chances for collaboration and increased influence	[92,98]

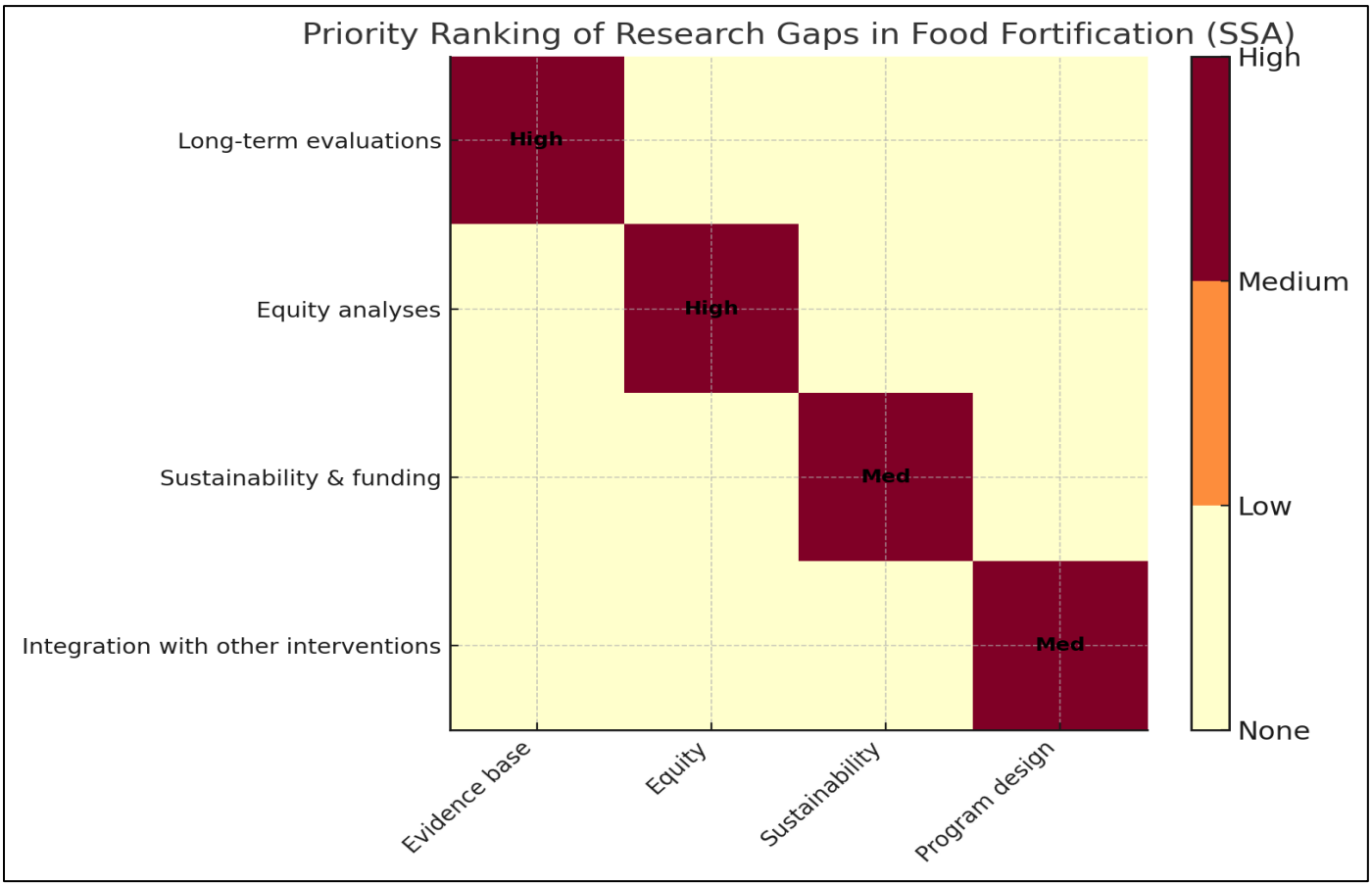

Fig 5 Sub-Saharan Africa's Research Gaps in Food Fortification by Domain are Ranked in Order of Priority.
Sources: Pachón et al. (2015) [91]; Osendarp et al. (2021) [92]; Mkambula et al. (2020) [93]; Horton et al. (2008) [96].

- *High Priority (3):*

✓ Long-term evaluations → Evidence base
✓ Equity analyses → Equity

- *Medium Priority (2):*

✓ Sustainability & funding → Sustainability
✓ Integration with other interventions → Program design

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Table 10 Policy Recommendations, Important Questions, and Research Gaps in Food Fortification (SSA)

Research gap	Key Research Questions	Policy/Program Recommendations	Sources
Long-term assessments of the effects of fortification	• What long-term effects does fortification have on iodine status, vitamin A deficiency, and anemia over a period of ten or more years? [99–101] • What is the impact of fortification on maternal-child health outcomes across generations? [99,100]	• Create nationwide monitoring programs that monitor micronutrient biomarkers [100,101]. • In high-burden nations, provide funding for longitudinal cohort studies [99,101].	[99–101]
Fairness in results and access	• Which geographic, gender, and socioeconomic groups gain the most? [102,103] • Who is left behind—HIV-affected populations, IDPs, or the rural poor? [103]	• For small and medium-sized mills, mandate fortification [102]. • Incorporate LSFF with specific social protection initiatives (such as fortified rations for IDPs and refugees) [103].	[102,103]
Models of funding and sustainability	• Which cost-sharing models can guarantee long-term premix supply? [104,105] • How are domestic resources mobilized by governments for fortification labs and monitoring? [104]	• Establish cost-sharing between the public and private sectors [104]. • Include fortification in national nutrition and health budgets [105].	[104,105]
collaborating with additional interventions	• How do infection prevention, dietary diversity, and supplementation relate to fortification? [100,106] • Which combinations yield the highest health benefits at the highest cost? [100,106]	• Test out integrated nutrition packages that include dietary diversification, supplementation, and fortification [100,106]. • Promote collaboration between the fields of education, agriculture, and health [106].	[100,106]

X. CONCLUSION

Iron-deficiency anemia, vitamin A deficiency, iodine deficiency, and zinc deficiency continue to impair maternal and child health outcomes, making micronutrient deficiencies a persistent public health concern in Sub-Saharan Africa [107,108]. Implementation and equity gaps persist despite the broad adoption of fortification policies, such as universal salt iodization, iron and folate-fortified flour, and vitamin A-fortified oils [109–111]. Fortress is an intervention that is required but insufficient. Its influence is limited by inadequate enforcement, sparse coverage in rural regions, and the exclusion of small-scale millers [110,112]. Furthermore, although fortification has demonstrated effectiveness in some situations (such as the decrease in neural tube defects in South Africa), there are few large-scale long-term assessments and inconsistent health outcomes, such as persistent decreases in anemia [113,114].

Programs for fortification need to be combined with more comprehensive nutrition and development plans in order to be as effective as possible. This calls for stepping up the enforcement of regulations, guaranteeing fair access for all socioeconomic groups, and integrating fortification into multi-sectoral strategies that connect trade (standards and food safety), health (maternal and child nutrition services), education (nutrition awareness), and agriculture (biofortification, dietary diversification) [111,115]. In conclusion, fortification is still one of the most economical nutrition interventions in SSA; however, countries must invest in cross-sectoral coordination, strong monitoring systems, and sustainable financing models to fully realize its potential [112,116].

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