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CLOSING THE VITAMIN A GAP IN ETHIOPIA THROUGH BIOFORTIFIED CROPS

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ABSTRACT

Vitamin A deficiency (VAD) remains a major public health concern in Ethiopia, especially among pre-school children. National efforts to address VAD – through vitamin A (VA) supplementation, food fortification, and dietary diversification – have been implemented but continue to face persistent coverage gaps, logistical challenges, and institutional constraints. In this context, VA biofortification has emerged as a potentially more sustainable and context-appropriate strategy for alleviating VAD within Ethiopia's smallholder farming systems. This study aimed at examining the landscape of VAD mitigation strategies in Ethiopia, with a particular focus on VA-biofortified crops. Findings from this study will help identify gaps in existing VAD policies and support more effective policymaking. A semi-systematic narrative review was employed to synthesize evidence from diverse sources, as quantitative analysis was not feasible due to limited and fragmented data. Relevant peer-reviewed literature, national datasets, organizational reports, and policy documents were identified through targeted keyword searches. The analysis assessed Ethiopia's progress in adopting VA-biofortified maize and orange-fleshed sweet potato (OFSP), with attention to agronomic performance, adoption determinants, and current implementation gaps. Ethiopia has released several VA-rich maize and OFSP varieties. However, adoption remains modest to low. Adoption barriers include weak certified seed and vine supply systems, high post-harvest losses, and consumer resistance linked to unfamiliar sensory attributes. For maize, farmer hesitancy, limited processing capacity, and negative perceptions of orange kernels further constrain uptake. Adoption of OFSP is hindered by low dry matter content in some varieties, inadequate post-harvest handling, and underdeveloped value chains. Despite these constraints, both crops hold substantial potential to improve VA intake in areas where VA supplementation and industrial fortification have limited reach. Realizing this potential will require strengthened seed and vine systems, expanded nutrition education, improved post-harvest management, and integration of biofortified crops into social protection programs. Enhanced coordination, institutional support, and sustained financing are essential for the government of Ethiopia to mainstream biofortification and achieve long-term VAD reduction and prevention in children.

Key words: Biofortification, Biofortified maize, Ethiopia, Orange-fleshed sweet potato, Vitamin A deficiency

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INTRODUCTION

Vitamin A deficiency (VAD) is a significant public health concern, particularly among children in low-income countries. It is a leading cause of preventable childhood blindness and contributes to premature mortality [1]. Clinically, VAD manifests as xerophthalmia, including night blindness. Chronic inadequate intake of VA generally leads to VAD, which can be prevented by a daily intake of approximately 500-700 µg of VA [2]. Vitamin A exists in two dietary forms, preformed VA and pro-VA carotenoids. Preformed VA (retinol, retinal, retinoic acid, and retinyl esters) is the most active and bioavailable form, found only in animal-source foods. In contrast, pro-VA carotenoids such as beta-carotene are found in plant-based foods [3]. Plant-based VA sources, however, are limited by their low carotenoid-to-retinol conversion rates, ranging from 6:1 to 26:1. Therefore, it is difficult to meet VA requirements through plant-based diets alone [4].

In sub-Saharan Africa, plant-based foods account for 70-80% of dietary intake by weight and calories. This is largely due to the agricultural practices of smallholder farmers who primarily produce staple crops such as maize, sorghum, millet, cassava, sweet potatoes, and beans. In contrast, animal-source foods constitute only 5-10% of daily caloric intake due to their high cost and limited availability [5, 6]. This has contributed to the persistent high prevalence of VAD in sub-Saharan Africa, ranging from 8.5% to 79% [7]. Among sub-Saharan African countries, this study focuses on Ethiopia, where the typical diet is predominantly plant-based.

Ethiopia's VAD burden remains high among children, despite multiple interventions being implemented by the Ethiopian government and international organizations. Against this backdrop, the present study examines the landscape of VAD mitigation strategies in Ethiopia, with particular attention to VA-biofortified crops. This study makes two key contributions. First, it informs Ethiopia's policymaking by providing updated evidence on current VA biofortification efforts and identifying policy gaps. This can support the design of more equitable and sustainable VAD reduction strategies. Second, the study contributes to the existing literature on nutrition-sensitive agriculture through a single-country analysis. While previous studies have examined similar interventions across countries, this study offers a focused assessment of Ethiopia.

MATERIALS AND METHODS

The study employed a semi-systematic narrative review approach to synthesize available evidence on VAD and VA-biofortified crops in Ethiopia. This approach was selected because relevant evidence is distributed across diverse sources, including peer-reviewed literature, national survey datasets, organizational reports, and policy documents. Moreover, the available studies differ in research design, and



demographic and geographic focus, making a quantitative synthesis infeasible. Therefore, the study sought to compile existing VAD intervention evidence, with particular emphasis on VA-biofortified maize and orange-fleshed sweet potato (OFSP). These two crops have been promoted as part of Ethiopia's nutrition-sensitive agriculture strategies.

Literature was identified through searches in PubMed, Web of Science, Scopus, AGRIS, and Google Scholar, as well as organizational sources such as the United Nations Children's Fund (UNICEF), the Global Fortification Data Exchange, the Food and Agriculture Organization, and the HarvestPlus. The search covered publications from 2000s to 2025. Search terms included: vitamin A deficiency, pro-vitamin A maize, biofortified maize, orange-fleshed sweet potato, biofortification, Ethiopia, and sub-Saharan Africa.

Peer-reviewed studies and gray literature (for example, government documents and program evaluation reports) were included if they provided empirical evidence in Ethiopian or comparable sub-Saharan African contexts. Materials were excluded if they contained only commentary information without supporting evidence. A key limitation of this study is the scarcity of longitudinal data directly assessing the nutritional impact of VAD interventions in Ethiopia. Despite this limitation, synthesizing evidence from reliable sources enabled a comprehensive understanding of Ethiopia's VAD situations and VA-biofortified crops, and identification of policy gaps.

RESULTS AND DISCUSSION

Vitamin A deficiency prevalence

Despite widespread recognition of VAD as a public health issue in Ethiopia, prevalence estimates vary across studies because of differences in methodology, geographic focus, and demographic characteristics. Some estimates place childhood VAD rates between 20% and 39% [7]. Others report that 14% of preschool-aged children and 10.9 % of school-aged children experience sub-clinical deficiency, while 37.7% of Ethiopian children exhibit deficient serum-retinol levels [8, 9]. A study shows that VAD is attributed to up to 80,000 child deaths annually and affects 61% of preschool-aged children [2]. Clinical VAD, measured by xerophthalmia, appears in 2.2% of preschool-aged children in Ethiopia. This figure surpasses the World Health Organization's threshold of 1.56% [2]. Those findings suggest substantial variations in VAD prevalence, complicating data interpretation to determine the actual VAD burden and potentially leading to misinformed policy decisions in Ethiopia. This situation, therefore, highlights the need for a unified VAD monitoring and surveillance system in Ethiopia.



Given the VAD situation, international organizations and the Ethiopian government have introduced several interventions to alleviate VAD. These efforts include promoting diversified diets with VA-rich foods, implementing VA supplementation for vulnerable populations, mandating food fortification with VA, and distributing VA-biofortified crop varieties [2, 8, 9]. However, the simultaneous implementation of multiple strategies has not ensured effective health outcomes, as they face gaps in coverage, compliance, and public awareness. Critics of the current strategies point to the low coverage of, and uneven access to VA supplementation and fortified foods, particularly among rural populations in remote areas [10]. Given Ethiopia's agriculture-centered economy, the promotion of VA-biofortified crops represents a more sustainable and contextually appropriate approach to VAD mitigation. Smallholders who rely on subsistence farming account for over 95% of Ethiopia's agricultural production [11]. Thus, VA-biofortified crops have the potential to offer more equitable access to this essential micronutrient.

Vitamin A biofortification strategy

Biofortification refers to the process of enhancing the nutritional content of crops through selective breeding or agronomic practices, with the goal of addressing micronutrient deficiencies [12, 13]. This strategy is particularly promising in low-income, agriculture-based countries such as Ethiopia, where staple crops (maize, wheat, teff, sorghum, barley, and sweet potatoes in Ethiopia) dominate consumption and production (Table 1). Recognizing the potential of biofortification, the government of Ethiopia has shown its intention to integrate biofortified crops into the national production and dietary diversification goals in the Food and Nutrition Strategy 2021-2030 [14]. In this context, two crops – maize and sweet potato – are of particular interest due to their dietary significance and agro-environmental adaptability for wide production. Despite their potential, VA-biofortified varieties of the two crops face distinct agronomic, sensory, and institutional challenges that affect their adoption and nutritional impacts in Ethiopia.

Maize

Maize (*Zea mays*), accounting for 30% of national cereal production, plays a central role in Ethiopian food systems. Approximately 76% of all maize produced is consumed at the household level, and its caloric contribution is particularly important to rural populations [13, 15]. Despite the crop's dominance in diets, most maize varieties grown in Ethiopia are white-kernelled, lacking pro-VA carotenoids. This has contributed to enhanced risks of VAD [16]. To address the issue, Ethiopia has released three VA-biofortified maize varieties with international supports as of 2025: CBC6, BHA5211, and BHA5212 [17].



Among these varieties, BHA5211 has demonstrated relatively stable yields across multiple environments, resistance to common diseases, and adequate levels of pro-VA carotenoids, reaching 9 µg/g. The National Variety Release Standing Committee released it as the first VA-rich maize variety in 2022. This signaled Ethiopia's push for biofortification with a major cereal crop [16]. However, empirical studies on the production, adoption, and consumption of the VA-biofortified varieties remain limited due to their recent introduction to maize producers and consumers. Consequently, quantitative data are needed to assess the potential contribution of VA-rich maize to future VAD reduction and prevention in Ethiopia.

For VA-biofortified maize to make meaningful impacts on VAD, it must be consumed regularly and in adequate quantities. In Ethiopia, most maize is produced for home consumption, as the market participation rate among maize producers is estimated at only 18% [4, 18]. Although this helps ensure that VA-rich maize is consumed directly by maize-producing households, it constrains access among urban consumers and non-maize producing households. Specific to the Ethiopian context, several barriers limit wider adoption and sustained consumption of VA-biofortified maize. One major constraint is the reluctance of smallholder farmers to adopt new maize varieties. Despite the availability of many improved maize varieties, adoption rates remain low at 27%. Factors such as limited education, small landholdings, agro-ecological diversity, and restricted social networks are linked to the low uptake of new maize varieties [15]. These issues highlight both the systemic barriers and the need for intensive promotion campaigns with clear information targeted to maize-growing regions.

Seasonality also poses a problem. Maize harvested for home use lasts for only about three months in southern Ethiopia, where farmland is relatively small [19]. Post-harvest losses due to inadequate storage further restrict its availability and continued consumption [4]. This underscores the importance of post-harvest management and complementary interventions during maize off-seasons. Another challenge involves access to certified maize seeds. Ethiopia's formal seed system remains underdeveloped, and informal channels continue to dominate seed distribution [10]. Evidence suggests that 85.7% of Ethiopia's cultivated land is planted with non-certified seeds, which will have implications for VA-biofortified maize [20-22]. The limited number of seed producers with uneven geographic coverage also exacerbates the issue, potentially discouraging maize variety adoption [10]. This indicates the need to strengthen formal seed distribution networks to support adoption and sustained production of VA-rich maize. However, achieving it will require long-term institutional commitment and adequate funding, which the Ethiopian government may have limited capacity to provide.

In addition, consumer preferences influence adoption of VA-biofortified maize. Ethiopian consumers generally prefer white maize, for its taste and cultural significance. The deep yellow or orange color of VA-rich maize – resulting from elevated pro-VA carotenoid levels in maize endosperm – is often associated with food aid or animal feed [21]. A similar pattern in consumer preference has been observed in Nigeria. VA-rich orange cassava faces resistance in Nigerian regions, where white varieties are dominant [22]. Such negative sensory perceptions may dissuade both producers and consumers to accept VA-biofortified maize. Therefore, intensive campaigns are critical to promote the link between the orange color in maize and its nutritional benefit.

Moreover, a comparable study in Nigeria shows that the awareness of biofortified maize was just 5%, significantly lower than that for biofortified sweet potato and cassava. The lower awareness of VA-rich maize was attributed to its later release than the two other crops [23]. The finding indicates that newly released VA-rich maize varieties require sufficient time to gain public familiarity and acceptance.

The effectiveness of biofortified maize depends on VA retention during post-harvest storage, processing, and cooking. Traditional Ethiopian maize dishes such as kita (flatbread) and genfo (porridge) may degrade carotenoid content due to cooking processes. Research shows that processed biofortified maize products retain as little as 20% of their original VA content after four months [24]. However, even with some VA loss, regular consumption of VA-rich maize still improves overall health outcomes. A study finds that biofortified maize increased children's immunity by 10% and improved growth by 8% [25]. Another study in Zambia demonstrates increased levels of serum beta-carotene among children who had consumed VA-rich maize. Yet, their serum retinol levels remained unchanged, likely due to their low baseline VAD and high infection rates [26]. These findings imply that VA-biofortified maize can serve as an important VA safety net, even though its effectiveness may vary.

To summarize, despite its dietary relevance and recent varietal advancements, maize biofortification in Ethiopia remains at an early stage. Its adoption and impact are constrained by farmer hesitancy toward new varieties, seasonal production limitations, weak seed systems, sensory preferences, and low public awareness. Addressing those barriers is essential for realizing the full potential of VA-rich maize in preventing and reducing VAD. Achieving this, however, requires coordinated strengthening of the maize value chain, including sustained institutional and financial commitment from the government of Ethiopia.

Sweet Potato

Sweet potatoes (*Ipomoea batatas*) are another key crop with promising potential to mitigate VAD in Ethiopia. The crop is extensively cultivated in southern and eastern



regions of the country, mostly by smallholder farmers who grow them in mixed cropping systems [27]. Also, the crop's adaptability to diverse agro-ecological zones and its role as a fallback food source during crop failure make it an essential food security crop [28-30]. Despite the crop's significance, its productivity remains low, averaging eight tons per ha. This figure is considerably below the average of 18 tons in Asian countries and estimated potential of 30-73 tons [28]. The varieties of sweet potatoes most commonly grown in Ethiopia are white- and light yellow-fleshed, which are very low in pro-VA carotenoids. To reduce the micronutrient gap, VA-biofortified sweet potatoes or orange-fleshed sweet potatoes (OFSP) have been introduced in Ethiopia since 2005 [31].

Initially released OFSP varieties were not widely accepted due to low root dry matter content, which negatively affected texture and taste. In 2009, improved OFSP varieties with higher dry matter were introduced, and since 2010 OFSP vines have been distributed to over 200,000 Ethiopian households [31]. Even with the vine distribution, adoption rates remain modest to low. In a central-southern region, OFSP occupied 19% of farm plots, while in southwestern areas, the figure was 3.7% [28, 31]. By comparison, conventional, white-fleshed varieties in southwestern areas accounted for 11.6% of cultivated land [31].

The limited adoption of OFSP is attributed to several agronomic and systemic factors [27, 31-33]. The dominant OFSP varieties in central-southern Ethiopia, Kulfo and Tulla, are not among the highest- or stable-yielding OFSP varieties currently available (Table 2). Farmers also face constraints such as limited access to disease-free planting materials, lack of pest control measures, and poor crop management practices, all of which contribute to yield gaps [28]. Studies have suggested that OFSP adoption is significantly influenced by farmers' awareness of nutritional benefits, their level of education, access to extension services, and proximity to vine centers. Farmers who understand the health benefits of OFSP are more likely to grow it, and those with better education are more capable of processing OFSP production information. Households more exposed to extension training also show a higher likelihood of adoption. Conversely, those located farther from vine multiplication centers have more difficulty obtaining planting materials in a timely manner [28, 31].

The availability and quality of planting materials are of particular importance for OFSP adoption. Currently, the majority of sweet potato vines are exchanged informally in Ethiopia, either through local markets or farmer-to-farmer sharing [27]. This informal system often fails to supply disease-free high-quality vines. Studies have noted that limited access to clean planting materials is a key reason why farmers are reluctant to expand OFSP cultivation [31]. As with maize, Ethiopia needs

to develop a reliable, well-regulated seed system for sweet potatoes to ensure the timely availability of quality vines. Without it, large-scale uptake of OFSP varieties is unlikely to be achieved.

Sensory qualities play an important role in the acceptance and continued use of OFSP. Texture, taste and color are the most important sensory qualities [34]. Farmers and consumers have expressed dissatisfaction with OFSP varieties that have low dry matter content, describing them as watery and unpalatable. The Kulfo variety, for example, has received low preference rankings in southwestern Ethiopia due to those traits (Table 2). By comparison, the white-fleshed variety Awassa 83 is favored for its superior cooking qualities, dry matter content of 30-33%, and higher yield [31]. In response, newer OFSP genotypes have been evaluated for their yield, dry matter, and beta-carotene content. Two genotypes, Ukr/Eju-10 and Ukr/Eju-13, emerged as top performers, demonstrating higher yield, favorable dry matter, and high beta-carotene content (Table 2). These genotypes were also highly ranked by farmers in preference trials and are expected to replace older OFSP varieties such as Kulfo [33]. Another genotype, Cacilia-22, has been recommended for release, based on its superior agronomic performance and acceptable sensory attributes [35].

Color has played a role in OFSP consumer perception as well. In rural areas, initial skepticism toward the unfamiliar orange color was reported [36]. However, nutrition education and exposure campaigns have proven effective in increasing OFSP acceptance. Informed consumers often perceive the orange color as a sign of higher nutritional value. Urban consumers, especially those responsible for child nutrition, have shown quicker acceptance of OFSP, following promotional efforts [17]. Taste tests and cooking demonstrations have further supported the perception shift by highlighting OFSP's flavor and health benefits [31].

Post-harvest handling presents another challenge. A large majority of sweet potato producers, up to 90%, store their harvest by leaving the crop in the ground until the crop is needed [37]. This practice, while common across sub-Saharan Africa, exposes the roots to pests and diseases, resulting in substantial losses. Damage rates of up to 40.2% have been reported, often caused by weevil infestation, mechanical injury, and lack of storage infrastructure. In addition, seasonal mismatches between production and market demand contribute to economic losses, especially for producers relying on wet markets [37].

Ethiopia's sweet potato value chain remains underdeveloped. At the wholesale level, grading, packaging, and value addition activities are minimal [34]. This discourages sweet potato producers from investing in quality improvements. Furthermore, the limited use of sweet potato beyond household consumption and its association with

poverty reduces the crop's market potential [34]. Yet, recent efforts to diversify the usage of OFSP have shown promising results.

A study examined integration of OFSP into staple products such as wheat bread and teff injera [38]. Since wheat and teff – both lacking pro-VA carotenoids – are widely consumed in Ethiopia, blending them with OFSP has the potential to increase VA intake. Evidence suggests that a 25g portion of 45% OFSP-blended wheat bread can provide up to 21.7% of the daily recommended VA intake for children aged 4-5 years. And a similar serving of injera can supply up to 16% [38]. These products were well-received in consumer sensory evaluations, and the blends also provided favorable profit margins. However, increasing such culinary integration efforts may be complicated by deep-rooted consumer preferences and competitions from other staple crops [34]. Importantly, sustained culinary integration depends on a consistent commercial supply of OFSP, which in turn is constrained by the current OFSP production and market limitations.

Taken together, while OFSP appears highly promising as a sustainable VAD intervention, its impact is limited by low adoption rates, weak vine distribution systems, post-harvest losses, and consumer resistance linked to sensory attributes. Targeted breeding, improved vine distribution, and effective communication strategies can meaningfully enhance its role in Ethiopia's efforts to combat VAD. Again, achieving this requires sustained policy commitment, coordinated investment, and substantial funding.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

Childhood VAD remains a critical public health issue in Ethiopia, due to a combination of plant-based diets, limited access to animal-source foods, and systemic gaps in nutrition interventions. While strategies such as VA supplementation, food fortification, and dietary diversification have been implemented, their effectiveness appears limited. In this context, biofortification presents a promising and sustainable solution that aligns with the country's agriculture system.

The analysis of VA-biofortified maize and sweet potatoes illustrates both the potential and the challenges of scaling up VA biofortification. Maize biofortification efforts are still in the early stage, with issues such as farmer reluctance, weak seed systems, seasonal limitations, and sensory resistance, slowing its progress. Similarly, the adoption of OFSP remains limited due to issues such as access to clean planting materials, post-harvest losses, and initial consumer skepticism about unfamiliar sensory traits. To advance the contribution of VA-biofortified maize and OFSP to national VAD prevention and reduction efforts, policy attention needs to shift from



short-term promotional efforts toward strengthening the broader systems that determine the crops' availability, quality, and sustained use.

First, a key priority is to improve the seed and vine supply chains, since both crops rely heavily on informal exchanges with inconsistent quality and seasonal gaps. Supporting local seed multipliers – farmer cooperatives, certified nurseries, or small seed businesses – could widen access to quality planting materials in a timely manner. At the same time, ongoing crop breeding programs should prioritize varieties with traits matching local sensory preferences as well as pro-VA carotenoid targets. Second, institutional clarity is essential. Responsible agencies should coordinate biofortification programs, monitor their progress, and align them with national nutrition goals. Concurrently, extension services could play a stronger role by providing more direct guidance on the production and storage of VA-biofortified varieties within the context of nutrition-sensitive agriculture.

Third, integrating biofortified crops into a public procurement system (for instance, school feeding programs and social protection plans) could provide reliable markets for producers and help increase consumption of VA-biofortified crops. This reduces sole reliance on household dietary changes. However, the integration strategy must be implemented along with public awareness campaigns to address misconceptions about biofortified varieties and promote their health benefits. Finally, sustained investment in post-harvest infrastructure and storage technologies can improve the year-round availability of biofortified crops. The government of Ethiopia may face technical and financial constraints in improving such infrastructure. Development partners working in nutrition-sensitive agriculture should navigate opportunities to provide technical and financial supports to Ethiopia.

Conflict of Interest

The author declares no conflict of interest.

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Not applicable



Table 1: Five-year average production of major crops in Ethiopia

Crop	Average annual production (2018–2022)
Maize	9.9 million ton
Wheat	5.6 million ton
Teff	5.5 million ton
Sorghum	5.1 million ton
Barley	2.4 million ton
Sweet potato	1.2 million ton
(Source) Food and Agriculture Organization	

Table 2: Characteristics of selected, orange-fleshed sweet potato varieties

Variety	Yield (ton/ha)	Dry Matter (%)	β-carotene (mg/100g)	Farmer preference Rank
Alamura	22.6 - 31.4 §	31.8	-	2
Carrot Dar	19.6	30.2	10.5	12
Dilla	23.1 - 27.8	32.4	-	1
Kabode	18.7 - 22.7	30.3	-	3
Kulfo	10.7 - 27	22.5 - 22.9	8.3	6 - 8
Res/Pip-21	22.7	30.3	2.4	5
Res/Tem-14	20.6	31.5	8.5	4
Res/Tem-23	10.7	24.8	7.3	10
SPK004/6	16.4	29.1	9.6	9
SPK004/6/6	20.4	30.2	8.5	6
Tainung-15	17.1	28.1	10.3	3
Tulla	17.9	28.5	-	5
Ukr/Eju-10	28.7	31.9	12.4	1
Ukr/Eju-13	26.8	31.4	9.5	2
Vita	15.2 - 20.8	29.6	-	4 - 5
(Source) 27, 31-33 § measurements were rounded to one decimal point				

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