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Role of nutrition-sensitive agriculture in enhancing sustainable humanitarian assistance: Evidence from orange-fleshed sweetpotato interventions in Kenya

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A B S T R A C T

The increasing frequency of climate-related shocks in arid and semi-arid regions has subjected local populations to cyclical livelihood disruptions and poverty traps. Humanitarian assistance is key to sustainable livelihoods in such regions, but this has largely been in the form of emergency aid. Sustainability concerns and public fiscal burden have necessitated a shift towards resilience building. Such interventions include biofortification, an important nutrition-sensitive agricultural approach that can sustainably improve food and nutrition security among vulnerable populations. However, there is limited evidence of success and lessons for scaling this approach. Using a sample of 636 households drawn from three arid and semi-arid counties in Kenya, this study uses a doubly robust estimator and non-parametric methods to investigate the effect of promoting vitamin-A-biofortified sweet potato as a nutrition-sensitive, climate-smart agricultural intervention to improve nutritional outcomes in humanitarian settings. We find that interventions combining demand-creation strategies and access to biofortified planting material significantly enhance nutrition knowledge and household nutrition indicators such as dietary diversity and food security. Individual interventions that either create demand or provide access to planting material enhance nutrition awareness but do not lead to primary nutrition outcomes such as dietary diversity. Lastly, enhancing access to planting material leads to higher nutritional outcomes compared to demand-creation strategies carried out in isolation.

1. Introduction

As climate impacts intensify, weather-related shocks have become more frequent, especially in regions characterized by arid and semi-arid climates. These regions are some of the most at risk in terms of agricultural losses, and food insecurity remains a key challenge (Pretty et al., 2011). For instance, over five million people living in the arid and semi-arid lands (ASALs) of Kenya face acute malnutrition (IPC 2023), representing about 32 percent of the ASAL population in the country. The region faces combined effects of weather-related shocks such as droughts and floods as well as conflict and insecurity, disrupting livelihoods and leaving the region fragile. The increasing frequency of such shocks has left people in these regions stuck in vicious cycles of poverty and dependent on humanitarian aid.

Emergency aid to preserve the lives of the most affected population segments is the most common form of humanitarian assistance in ASALs (Kurdi & Ruckstuhl, 2023). Evidence on the economic impacts of such approaches to humanitarian assistance is varied, with some studies showing positive returns due to multiplier effects (Gentilini, 2014) or nutrition outcomes (WFP, 2014), while others point to negative impacts such as crowding out of local production and market systems, and localized inflation (Gairdner et al., 2011; Idris, 2016). Emergency aid is criticized for its short-term nature, with sustainability and resilience building being shelved for simple solutions such as emergency food and cash transfers (Mbow et al., 2019). Such criticism is leading to a shift in humanitarian assistance, from approaches focused on emergency aid to those that build resilience, where sustainable solutions to mitigate impacts of future disasters are amplified in addition to emergency responses (Manis, 2018).

Nutrition-sensitive agriculture (NSA) is a food-based approach to addressing malnutrition and micronutrient deficiency that is increasingly being supported by governments, donor agencies and development partners to achieve their development goals (Ruel, 2001; Ruel et al., 2018). Nutrition-sensitive programs encompass several sectors spanning agriculture, health, social protection, early child development, education, and water and sanitation (Ruel & Alderman, 2013). While such

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interventions are critical for ASALs to combat food and nutrition insecurity, resilience to shocks such as dry weather spells, droughts, and floods, which are prevalent in these regions, must be an important component of NSA interventions. For instance, while biofortification is recognized as a feasible and cost-effective NSA approach (Bouis & Saltzman, 2017), its effectiveness would be greatly curtailed if the biofortified technologies themselves and interventions to promote their adoption are not resilient to the recurrent shocks prevalent in ASALs (Low et al., 2020; Mwanga et al., 2021; Thiele et al., 2017). Recently, the International Potato Center (CIP) and the World Food Programme (WFP) collaborated to integrate orange-fleshed sweet potato (OFSP),[1] a rich plant-based source of pro-vitamin A (beta-carotene) (Low & Thiele, 2020), into humanitarian programming interventions in the ASALs of Kenya and Uganda. These nutrition-sensitive, climate-smart agricultural interventions were implemented within the broader project called "development and delivery of biofortified crops at scale" (DDBIO), which aimed to improve diets of millions of households in Africa and Asia by scaling up biofortification (CIP, 2019).

Despite the growing body of literature on nutrition-sensitive agriculture, there is a dearth of evidence on the success and cost-effectiveness of these interventions in enhancing nutrition outcomes within the context of humanitarian assistance. Using data from the implementation of the DDBIO project, this study evaluates its impact on select nutritional outcomes in ASAL counties of Kenya. Further, the study assesses the effectiveness of separate interventions that target either the demand- or supply- side enablers of biofortification, as well as combinations of these interventions. Assessing the individual interventions as well as their combined effects provides important insights to guide the scaling up of nutrition-sensitive climate-smart agricultural interventions for humanitarian assistance.

2. Background

2.1. Food insecurity and humanitarian assistance in the ASALs of Kenya

A combination of factors including cyclical shocks, conflict, and insecurity, continue to depress food and nutrition outcomes for people living in the ASALs of Kenya. It is estimated that over 4.4 million people in these regions (representing about 27 % of the population) were facing acute food insecurity as recently as early 2023 (IPC 2023). This situation is expected to have worsened with the recent floods affecting the regions, with an estimated 27,205 households (about 150,000 people) being displaced by flash floods in ASAL counties in Kenya by November 2023 and the El Niño phenomenon yet to peak later in the year (ACTED, 2023). Similarly, acute malnutrition across the ASALs has worsened, with about 970,000 children below five years of age and 142,000 pregnant and lactating women requiring treatment in 2023 alone (see Fig. 1 on the food insecurity situation in the Kenyan ASALs).

Amidst these challenges, humanitarian assistance continues to play a key role in sustaining livelihoods in ASAL regions. Direct delivery of food assistance has been the main vehicle for such humanitarian efforts, with recent efforts shifting to a combination of food aid and cash transfers (Gentilini, 2014). To embed resilience building into humanitarian assistance, this approach is evolving into an integrated strategy encompassing climate-resilient agriculture, market support, and social protection. The aim is to support inclusive food systems that both respond to emergency situations and lessen the impact of such shocks in the long term (WFP, 2023).

2.2. Sweet-potato-based humanitarian interventions in Kenyan ASALs

Sweet potato (*Ipomoea batatas* (L.) Lam.) is a climate-resilient crop grown by many households across sub-Saharan Africa. The crop is critical for food security in these regions, especially during crises such as drought and floods, given its resilience to harsh weather and short maturing period (Gatto et al., 2021; Manners et al., 2021; Motsa et al., 2015). For instance, sweet potato can be harvested after only 90–110 days, which is important for ensuring a supply of food during emergency recovery periods, such as post-flood periods (Gatto et al., 2021). The crop can also play an important role in soil conservation by acting as a cover crop to enhance moisture retention and prevent surface runoff and by replenishing soil carbon through residue retention (Kumar et al., 2021). The roots and leaves of sweet potato, both of which are consumable, have diverse nutrition benefits including bioactive carbohydrates, proteins, carotenoids, flavonoids, anthocyanins, phenolic acids and minerals (Alam, 2021). Additionally, the vitamin-A-biofortified orange-fleshed sweet potato (OFSP) varieties have been shown to significantly increase serum retinol concentrations in young children (Low et al., 2007; 2017). Recent breeding efforts have led to the release of OFSP varieties that are more resilient to drought (see Gitore et al., 2021; Low & Thiele, 2020).

Evidently, sweet potato offers an immense opportunity for integration into NSA interventions in ASAL regions. Exploring diversified systems in combination with other resilient crops, such as those identified as priority crops under the vision for adapted crops and soils (Fredenberg et al., 2024), can go a long way in embedding sustainability in humanitarian assistance in these regions. Further, integrating value chain support into these interventions, such as sweet potato storage and processing facilities (see Low & Thiele, 2020; Moyo et al., 2022; Tedesco & Stathers, 2015) would lead to enhanced resilience and contribute to development of the Kenyan ASALs as envisaged in Vison 2030 and the country strategic plan (Kenya Vision 2030, 2023). The DDBIO project sought to leverage some of these impact pathways to enhance the sustainability and resilience of humanitarian assistance in the ASAL regions of Kenya. Interventions were implemented within the context of other WFP food and cash-based interventions (WFP, 2023).

The targeted interventions aimed at addressing both supply- and demand- side enablers to OFSP uptake and utilization. On the demand-side, strategies encompassing social behavior change communication (SBCC) aimed at creating nutrition awareness and demand for OFSP, while those targeting the supply-side aimed at enhancing access to OFSP planting material. Targeted SBCC interventions included club membership for caregivers of children below the age of five years, called healthy living clubs (HLCs), where members were offered a nutrition training curriculum. Another SBCC strategy involved distribution of a CIP innovation called the healthy-baby toolkit (HBT), a feeding kit aimed at guiding caregivers on the appropriate weaning practices for babies (CIP, 2020). Some beneficiaries were exposed to both demand-side interventions while some only received one intervention. Supply-side interventions to enhance accessibility of OFSP material included provision of free vines for beneficiaries to plant, linking beneficiary households with decentralized vine multipliers (DVMs), and provision of agro-advisory services through partnerships with the county and national ministries of agriculture.

2.3. Impact pathways

Our main objective was to evaluate the effect of the NSA interventions implemented under the DDBIO project on key intermediate and primary nutrition outcomes (see section 3.2 for definitions). On the demand-side, project beneficiaries were exposed to SBCC interventions

[1] Orange-fleshed sweet potato (OFSP) refers to a range of sweet potato varieties that have been selected for high beta-carotene content, a provitamin A compound that is converted to retinol (vitamin A) in the body. OFSP varieties have been shown to significantly increase serum retinol concentrations among consumers and can be part of long-term sustainable and food-based approaches to fight malnutrition in developing countries (Van Jaarsveld et al., 2005). Over time, new OFSP varieties have been bred to include other traits such as drought tolerance (Gitore et al., 2021), making these varieties suitable for addressing malnutrition in areas with erratic rainfall.

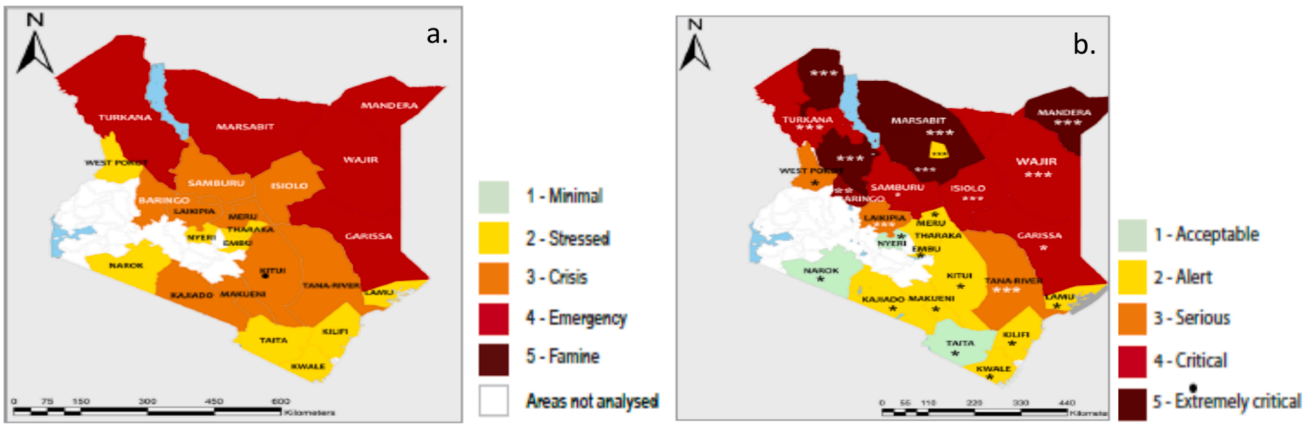

Fig. 1. Food [a] and nutrition [b] insecurity in ASALs of Kenya (.
Source: IPC, 2023). *Stars indicate regions of data paucity where estimates were largely used for indicators of food and nutrition insecurity status

such as HLC and HBT, leading to increased awareness about malnutrition, its causes, and foods that combat malnutrition. This included information on vitamin A deficiency and foods that promote vitamin A absorption, such as OFSP. Such interventions enhance beneficiaries' nutrition awareness and demand for nutrient-dense foods, including OFSP. Conversely, supply-side interventions, such as the establishment of DVMs, dissemination of vines to pregnant and lactating mothers in health clinics, etc., enhance access to OFSP vines for household own production.

Various pathways to impact are expected from these interventions. First, demand-side interventions directly lead to improved nutrition and vitamin A awareness among targeted beneficiaries (intermediate outcomes). Given the increased nutrition awareness, these participants then actively incorporate nutrient-dense foods in their diets, either through market purchases or their own production, leading to higher household dietary diversity and reduced incidence of food insecurity (primary outcomes). The supply-side interventions complete the loop, by making both OFSP vines and roots accessible within the project intervention areas. In addition, households that benefit from the supply-side interventions only may achieve higher primary outcomes, even in the absence of demand-side interventions, through their own production of OFSP roots.

Three distinct impact pathways from the project implementation strategy emerge: [1] direct impact from demand-side interventions to intermediate outcomes; [2] direct impact from supply-side interventions to primary outcomes; and [3] indirect impacts from demand-side interventions to primary outcomes, with the intermediate outcomes acting as mediator variables. In the case where project beneficiaries were not exposed to both demand- and supply- side interventions, market mechanisms and social networks play an important role in enabling access to both the OFSP vines for own production or roots for home consumption, in the case of the third impact pathway. These mechanisms may also lead to spillover to non-beneficiaries within the intervention areas, an important outcome related to technology diffusion (see Gatto et al., 2023). However, here we focus on evaluating project impacts on reached beneficiaries and adopt a sampling strategy that limits biasing obtained results from such spillovers (see section 3.1).

3. Methods

3.1. Data

The study was carried out in January 2023 in three ASAL counties of Kenya, Makueni, Tana River and Garissa. The three counties were part of the initial DDBIO project intervention areas, starting in 2021 (see Fig. 1 for the location of these counties and their food insecurity status). Project beneficiaries across sub-counties, wards and villages in the three selected counties were identified with the help of local WFP staff and project implementation partners, and probability proportional to size (PPS) sampling used to select the study participants across these administrative units. A similar strategy was employed to select households in wards where the project was not implemented to form a comparison group in the impact analysis strategy. While the DDBIO interventions were implemented within a broader context of other WFP food- and cash-based interventions (WFP, 2023), the use of administrative wards for selecting treatment and comparison groups limits spatial heterogeneity between the two groups, implying similar exposure to covariate climatic shocks and targeting strategies for emergency aid. The sampling strategy resulted in a total of 417 project beneficiary households and 219 non-beneficiary households, spread across the study area as shown in Table 1 below.[2]

The survey instruments were piloted and administered at the household level by trained enumerators. Ethical clearance for the study was obtained from the National Commission for Science, Technology and Innovation (NACOSTI) of Kenya (license number: NACOSTI/P/23/23228).

Table 2 reveals significant differences in pre-treatment household characteristics across treated and non-treated households, as well as across intervention categories. Households with better educated heads and with access to off-farm incomes are significantly exposed to more interventions. About 26 % of the households with at least one member having access to salaried employment are exposed to all three interventions; only 7.8 % of households reporting access to non-farm income are not exposed to any intervention at all. Higher asset ownership is associated with participation in two or more interventions. The percentage of households growing OFSP across those with no exposure and exposure to one or two interventions is similar. However, the percentage of households growing OFSP is almost universal (97.9 %) among those exposed to all three interventions. Many of these differences in household characteristics are significant across the intervention categories (see last column of Table 1), pointing to our inability to randomize treatments. The analytical strategy used in this study (discussed in detail in section 3.3) aims to address biases emanating from this non-randomization of treatments.

3.2. Variable definitions

Outcome indicators.
The study considers four key nutrition outcomes: two related to

[2] In line with the estimation strategy that uses the number of interventions received as the key predictor variable, the data are categorized by the number of interventions received.

Table 1
Description of the variables.

Variables	Overall (n = 636)	Interventions received by household (HH)				
		None (n = 219)	One (n = 220)	Two (n = 150)	Three (n = 47)	p-value
Average age of HH head	36.06 (13.42)	39.33 (15.70)	35.02 (12.29)	32.88 (10.71)	35.77 (11.80)	0.00**
Household size	5.21 (2.07)	5.46 (2.26)	5.20 (2.03)	4.9 (1.86)	5.14 (1.91)	0.08
Households with pregnant women (%)	3.30	3.65	4.09	2.00	2.13	0.68
Household heads' years of schooling	8.51 (4.21)	7.10 (4.91)	9.03 (3.86)	9.4 (3.21)	9.77 (3.34)	0.00**
Access to off-farm income (%)	8.49	7.76	10.00	7.33	8.51	0.80
OFSP consumption in last 7 days (%)	6.92	5.43	6.90	6.78	13.64	0.55
Growing OFSP currently (%)	50.16	46.79	47.62	43.54	97.87	0.00**
Agriculture is a principal activity (%)	73.90	76.26	69.55	72.67	87.23	0.05
Sold agriculture or livestock products (%)	27.67	28.31	30.00	24.0	25.53	0.63
Taken salaried employment (%)	18.08	14.61	23.18	13.33	25.53	0.02**
Took casual labor (%)	30.66	27.85	33.18	30.67	31.91	0.68
Been involved in informal business (%)	16.19	15.07	19.09	12.67	19.15	0.34
Been in self-employment (%)	24.69	23.74	25.45	25.33	23.40	0.97
Asset index	0.001 (1.00)	−0.02 (0.93)	−0.05 (0.76)	0.09 (1.30)	0.04 (1.17)	0.58
Ln total value of Assets	7.49 (1.58)	7.04 (1.73)	7.75 (1.66)	7.61 (1.57)	7.14 (0.16)	0.51
Market participation (%)	38.21	46.12	35.00	29.33	44.68	0.00**
Planting of roots, tubers, bananas (%)	46.86	49.77	41.82	41.33	74.47	0.00**
Area allocated to sweet potato (%)	14.36	13.98	18.29	10.93	11.38	0.38
Distance to the main source of water (walking minutes)	28.42 (36.29)	26.63 (32.26)	27.60 (38.43)	30.47 (39.23)	34.11 (34.22)	0.52
Toilet ownership, yes (%)	88.68	80.37	90.45	95.33	97.87	0.00**

Standard deviation in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

changes in nutrition awareness (intermediate nutrition outcomes), i.e., vitamin A knowledge score (VAKS) and nutrition knowledge score (NKS); and two related to changes in household food security indicators (primary nutrition outcomes), i.e., household dietary diversity score (HDDS) and household food insecurity access scale (HFIAS) (see Table 2). The main hypothesis of the study is that recipients of interventions that only address one side of barriers to OFSP use, i.e., related to either demand or supply, may only achieve some nutrition outcomes, but not all (Grant et al., 2022).

Table 2
Description of outcome variables.

Variable	Overall (n = 636)	Level of participation (Interventions)				p-value
		No (n = 219)	One (n = 220)	Two (n = 150)	Three (n = 47)	
HDDS	6.23 (3.20)	6.32 (3.06)	6.02 (3.41)	6.04 (3.38)	7.36 (1.63)	0.04**
HFIAS	9.47 (6.72)	9.65 (6.62)	9.92 (6.81)	9.29 (6.81)	7.06 (6.16)	0.06
VAKS						
Low (<4)	353 (55.5)	156 (71.2)	116 (52.7)	68 (45.3)	13 (27.7)	0.000***
High (>=4)	283 (44.5)	63 (28.8)	104 (42.3)	82 (54.7)	34 (72.3)	
NKS						
Low (<8)	116 (18.24)	59 (26.94)	33 (15.00)	19 (12.7)	5 (10.6)	0.000***
Moderate (8–13)	288 (45.28)	101 (46.12)	102 (46.46)	64 (42.7)	21 (44.7)	
High (14–24)	232 (36.48)	59 (26.94)	85 (38.64)	67 (44.7)	21 (44.7)	

Standard deviation in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

The intermediate nutrition outcome variables, VAKS and NKS, were constructed using key nutrition and child-feeding knowledge indicators: questions specific to construction of the VAKS variable included a dummy indicator for whether the respondent had heard about vitamin A; questions related to importance of vitamin A in the body; and the number of foods they knew that were rich in vitamin A. The first question contributed one point to the index and the last two contributed two points each for a final VAKS ranging from 0 to 5. The NKS variable was also constructed in a similar manner but encompassed broader questions relating to knowledge of food types and their functions in the body, and breastfeeding and weaning practices, etc. (see Grant et al., 2022).

The primary nutrition outcome indicators, HDDS and HFIAS, were constructed in a similar fashion to the intermediate ones. The HDDS was derived from indicator variables of household consumption of 13 food groups using a 24-hour recall, with the score adding up to 13 based on food groups consumed within this period. The HFIAS, on the other hand, is constructed from nine questions based on food insecurity experienced and the frequency of such occurrences over the previous 30 days (Coates et al., 2007). A score of 0–3 is assigned to each of the nine scenarios based on occurrence and frequency, resulting in a continuous score ranging from 0 to 27, with higher score indicating worse food insecurity.

Explanatory variables.

The three project interventions discussed previously, i.e., healthy living clubs (HLCs), healthy baby toolkit (HBT) and OFSP vine provision (OVP), were the main treatment indicator variables in the study. A subset of the sampled beneficiaries received all three interventions with others receiving only one or two interventions (see Table 1). It is important to note that spillovers within intervention areas may have led to exposure to more interventions than those applied during the project implementation. To construct the variable on number of interventions, we asked respondents to indicate all the project interventions they had been exposed to, regardless of the source (i.e., whether they received OFSP vines from CIP/WFP/county partners, or from fellow farmers).

There were seven possible combinations for the treatment variables, i.e., no intervention, HBT only, OVP only, HLC only; HBT plus OVP, HBT plus HLC, and OVP plus HLC. However, dividing the data into seven categories leads to disintegration of the sample, especially for OVP combinations given the small sub-sample for this intervention. Therefore, we only use these categories in non-parametric sample proportion tests, and not in formal econometric analysis. For the latter, the seven

categories are grouped into four main categories: 1) no intervention; 2) at least one intervention; 3) two interventions; and 4) three interventions, yielding 0–3 range score variable.

The evaluation strategy adopts a dose–response approach, with the level of treatment received (0–3) mapped onto the level of nutrition outcome achieved (Bia & Mattel, 2008). We hypothesize that a higher level of intervention exposure leads to higher nutrition outcomes, through a combination of direct and indirect impact pathways as discussed previously (see section 2.3). Additionally, we hypothesize that supply-side interventions, such as OVP, have a higher impact on nutrition outcomes compared to demand-side o, such as HLC or HBT, since the former directly increases the adoption of nutritious foods (OFSP) through the beneficiaries' own production. We tested the first hypothesis using a dose–response treatment effect econometric model (see Stata, 1999), and non-parametric kernel density functions for the second hypothesis.

In addition to the treatment indicators discussed above, we controlled for variables expected to confound impact estimation. For instance, proximity to main markets and DVMs where OFSP roots and vines are marketed, as well as to clinics where HLC meetings took place and HBTs were distributed, may confound impact measurement by biasing beneficiaries into treatment through exposure (exposure bias). Other observable variables that bias beneficiaries towards selecting the treatment (selection bias) include household head characteristics such as age, gender and education, household wealth such as asset ownership, living conditions, off-farm incomes, access to agro-advisory services, participation in markets, and whether the household was growing OFSP, etc. Most of these are directly observed and included in the estimation, while others are constructed as composite variables. The wealth index, for instance, is a composite variable of household assets, and access to water for household uses and housing conditions, constructed using principal component analysis (PCA) (see Córdova, 2008).

3.3. Empirical estimation

Enablers of project participation

We first estimated determinants of exposure to the three interventions, i.e., HLC, HBT and OVP. While these treatments were exogenously introduced to the study beneficiaries, we hypothesize similar factors to drive participation in each. For instance, proximity to health clinics may enhance caregivers' participation in HLCs as well as the likelihood of receiving HBT, while also enhancing exposure to OFSP roots through the established gardens in such facilities. Similarly, access to nutrition information through HBT or HLC may generate demand for OFSP vines, implying path dependency (Mulwa et al., 2017). We therefore hypothesize a correlation in the error terms of the three equations for intervention exposure, and specify a multivariate probit (MVP) model for analyzing determinants to intervention exposure (see Mulwa et al., 2017 for an application).

Effect of project participation on nutrition outcomes.

To determine the effect of the interventions on nutrition outcomes, we faced the challenge of non-randomization into treatment. Several approaches have previously been used to correct for biases arising from non-randomization when evaluating impact (Bezu et al., 2014; Mulwa et al., 2023; Mulwa & Visser, 2020; Shiferaw et al., 2014; Teklewold et al., 2013). Among these, doubly robust estimators are gaining prominence given their ability to produce robust results even when either the selection or outcome equation is mis-specified (Emsley et al., 2008; Wei et al., 2022). This approach combines an outcome regression with a model for exposure to treatment (based on propensity score methods) in estimating the effect of the treatment exposure on the outcome (Funk et al., 2011; Kihiu & Amuakwa-Mensah, 2021). The inverse probability weighting regression adjustment (IPWRA) model has an added advantage of correcting for unbalanced covariates across treatment and control observations by applying inverse probability weights (IPW) in the first stage of modelling for exposure to treatment, then using a regression adjustment (RA) in the second outcome regression stage (Wei et al., 2022). We therefore applied the IPWRA method to estimate the effect of exposure to nutrition interventions (HLC, HBT and OVP) on the key household nutrition outcomes (VAKS, NKS, HDDS and HFIAS).

The IPW estimator utilizes weighting to model the probability of being treated, without making any assumptions regarding the functional form of the outcome model. The estimator assigns each observation a weight equal to the inverse of the probability of being in the treatment sample, i.e., $1/p_i$ for the treated and $1/1-p_i$, based on the covariates affecting exposure to treatment $\boldsymbol{X}$. On the other hand, the RA estimator utilizes a regression analysis to predict potential outcomes for the different treatment levels adjusted for outcome covariates, $\boldsymbol{X}$. The estimated average treatment effects (ATEs) are differences in the average estimated potential-outcome means (POMs) for treated and untreated units while the estimated average treatment effects on the treated (ATETs) are averages of the predicted outcomes over the treated observations (Stata, 1999). The obtained treatment effects are still confounded by potential bias towards treatment selection as the estimator models the outcome equation without any assumption on the functional form of the treatment model.

In IPRWA, the inverse of the treatment-probability weights from the IPW are used to estimate regression coefficients in the RA, which are then used to compute POMs. Following Wooldridge (2010), we first estimated the propensity score, p(w), for the probability of being exposed to intervention treatments based on X;

$$p(x) = P(t = 1/X) \tag{1}$$

Next, we used linear outcome functions to estimate α and β parameters using inverse probability weighted least squares as below:

$$Min_{\alpha_1,\beta_1} \sum_{i=1}^{N} (y_i - \alpha_1 - \beta_1 X_i) \Big/ p(X_i, \widehat{\Upsilon}) ift = 1 \tag{2}$$

$$Min_{\alpha_0,\beta_0} \sum_{i=1}^{N} (y_i - \alpha_0 - \beta_0 X_i) \Big/ 1 - p(X_i, \widehat{\Upsilon}) ift = 0 \tag{3}$$

The average treatment effect is then obtained as:

$$ATET_{IPRWA} = N_T^{-1} \sum_{i=1}^{N_T} [(\widehat{\alpha}_1 - \widehat{\beta}_1 X_i) - (\widehat{\alpha}_0 - \widehat{\beta}_0 X_i)] \tag{4}$$

where $\widehat{\alpha}_1, \widehat{\beta}_1$ and $\widehat{\alpha}_0, \widehat{\beta}_0$ are the estimated inverse probability weighted parameters for the treatment and non-treated group, respectively; N_T is the number of treated observations in our sample.

Robustness check.

The IPWRA estimation described above only controls for bias emanating from observable characteristics (included in the X vector), and residual bias related to unobservable characteristics cannot be ruled out. This may include unobservable idiosyncratic aspects such as personal ambition, nutrition consciousness, exposure to other unspecified nutrition programs, etc. For a robustness check to the estimation using IPWRA as discussed above, we also implemented a two stage residual inclusion (2SRI) estimation (also known as the control function approach) to account for residual bias (Murtazashvili & Wooldridge, 2016). The estimation process involves capturing residuals from the first estimation of the selection equations (probability of participating in the interventions) and including them in the second outcome equation as additional regressors, including the main dependent variable in the selection equation (see Mulwa & Visser, 2020 for an application).

For our study, the dependent variable in the selection equation is ordered from 0 to 3 with non-beneficiaries receiving no intervention at all, while beneficiaries receive either one, two or three interventions. An ordered logit model is thus used in the first stage estimation of the selection equation, while ordinary least squares (OLS) regressions are

estimated in the second stage using the outcome variables defined in Section 3.2. A dummy variable—whether a household had a child aged between two and five years at time of data collection— is also used as a selection instrument in the first stage. This is informed by the targeting mechanism at the project implementation stage where pregnant and lactating mothers were targeted during ante- and post- natal clinics, and therefore these children would now be about two to five years of age. Simple falsification tests showed that this is a valid instrument, as it explains participation in the interventions but not the key outcome variables.

4. Results and discussion

First, we present results from the multivariate probit estimation of factors correlated with participation in DDBIO interventions in the project area. Next, we discuss results from IPWRA and 2SRI estimations of the effects of participation in different number of interventions on select household nutrition outcomes. Finally, we present results of the non-parametric analyses of effect of demand-side (HBT plus HLC) and supply-side (OVP) interventions.

4.1. Enablers for NSA participation

Consistent with previous studies on gender and exposure to agricultural innovations (Mulwa et al., 2023; Tibesigwa & Visser, 2016), we find that men are more likely than women to access OFSP vines. Although OFSP demonstration gardens are planted in health clinics that are more frequently visited by women, there may be spillover to the larger community and subsequent higher demand for the vines from men. Women are more likely to be exposed to the HLC treatment, which is consistent with the study strategy of targeting pregnant and lactating mothers for participation in the healthy living clubs. Similarly, consistent with similar studies, we find a quadratic relationship between the age of household heads and the probability of exposure to nutrition awareness (i.e., through HBT) (Mulwa et al., 2023), indicative of life-cycle effects. Younger household heads are likely to be more involved in productive activities, including agriculture, are more nutritiously conscious, and for female-heads, more likely to be of reproductive age and attuned to the nutritional needs of young children.

Among other socio-demographic variables, household size was also found to significantly explain exposure to HBT treatment (Table 3). Specifically, larger household sizes were less likely to have access to HBT kits, perhaps pointing to the negative correlation between household size and socio-economic outcomes (Adeniji-Oloukoi et al., 2013; Tibesigwa & Visser, 2016). Households with a pregnant household member were found to be less likely to receive HLC training, perhaps since such members were targeted during the initial project inception, with beneficiaries now more likely to be in the category of those households with children less than 5 years of age. The positive association between this variable and HBT treatment indicates this is likely.

Growing sweet potato within the previous three years was positively associated with exposure to OFSP vines, perhaps pointing to project targeting strategy of sweet potato growing areas. Households that received OFSP vines within the project timeframe were highly likely to be already growing sweet potato at the time of the study, consistent with previous studies (Mulwa et al., 2023) showing that exposure to nutrition awareness activities significantly predicted consumption of OFSP, either through beneficiaries' own production or market participation. Other findings show that wealthier households (proxied by a high asset index score) were also more likely to receive HLC training and to access OFSP vines. Relative to the base county of Garissa, residents of both Tana River and Makueni counties were also more likely to be exposed to demand creation strategies such as HLCs and HBTs.

Table 3
Results from a multivariate probit estimation of determinants to intervention participation.

	(1)	(2)	(3)
Variables	HBT	HLC	OVP
Household head gender	0.150	−0.667***	0.536***
	(0.352)	(0.245)	(0.178)
Household head education	−0.0284**	0.0156	1.90e-05
	(0.0143)	(0.0254)	(0.0296)
Household head age	0.0873***	0.0212	0.0115
	(0.0253)	(0.0215)	(0.0271)
Household head age_squared	−0.000962***	−0.000450*	−0.000138
	(0.000282)	(0.000271)	(0.000242)
Household size	−0.100**	−0.0181	0.0420
	(0.0417)	(0.0278)	(0.0471)
Household has a pregnant	0.624**	−0.842**	−0.310
member	(0.288)	(0.360)	(0.399)
Asset index	0.0159	0.117***	0.128**
	(0.0458)	(0.0428)	(0.0529)
Distance to water source (	−0.000595	0.00327**	0.000646
walking minutes)	(0.00184)	(0.00148)	(0.00232)
Access to off-farm income	−0.114	−0.0686	0.123
	(0.205)	(0.146)	(0.222)
Household grew sweet potato	0.116	0.117	5.323***
in the last 3 years	(0.130)	(0.133)	(0.245)
Children < 5 years of age	0.469***	0.249*	−0.0430
	(0.114)	(0.129)	(0.122)
Makueni county	1.413***	0.830*	0.286
	(0.417)	(0.452)	(0.339)
Tana River county	0.751*	1.001**	0.196
	(0.388)	(0.476)	(0.262)
Observations	636	636	636

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

4.2. Effect of interventions on household nutrition outcomes

Intervention level and nutrition outcomes.

This section presents results from the IPWRA estimation (note that the coefficients have been expressed as percentage changes for ease of interpretation). Consistent with similar studies, the results show highly significant effects for nutrition interventions across the intermediate outcomes of vitamin A and nutrition knowledge (Adekambi et al., 2018; Gatto et al., 2023; Girard et al., 2021; Mulwa et al., 2023). Households that received one, two and three interventions achieved a vitamin A knowledge score (VAKS) higher than that of non-recipient households by 29, 45 and 74 percent, respectively (Table 4). Compared to a baseline of one intervention, households receiving two and three interventions

Table 4
Average treatment effect (ATE) results from IPWRA estimation.

Intervention dosage	Intermediate outcomes		Primary outcomes	
	Vitamin A knowledge	Nutrition knowledge	HFIAS	HDDS
Baseline: zero intervention received				
One	0.285**	0.105**	0.161	0.062
intervention	(0.115)	(0.043)	(0.092)	(0.091)
Two	0.450***	0.146***	0.151	0.151
interventions	(0.126)	(0.047)	(0.100)	(0.099)
Three	0.735***	0.146**	−0.221*	0.358***
interventions	(0.174)	(0.062)	(0.101)	(0.119)
Baseline: one intervention received				
Two	0.128*	0.037	0.005	0.070
interventions	(0.068)	(0.037)	(0.074)	(0.077)
Three	0.350***	−0.037	−0.294**	0.273***
interventions	(0.104)	(0.052)	(0.115)	(0.095)
Baseline: two interventions received				
Three	0.197**	0.001	−0.297**	0.189**
interventions	(0.090)	(0.051)	(−0.116)	(0.089)

Standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

achieved 13 and 35 percent higher VAKS, respectively, while those who had three interventions attained about 20 percent higher VAKS than those who had only two interventions. A similar trend was observed for the overall nutrition knowledge score (NKS), but only between the baseline scenario of no intervention versus either one or two interventions. The results suggest higher vitamin A and nutrition knowledge as the number of interventions increase. Households that received the three interventions of HBT, HLC and OVP, i.e., both demand- and supply-side enablers, are shown to achieve the highest nutrition awareness outcomes.

The combination of three interventions was the only treatment with significant differences in primary nutrition outcomes for recipients compared to baseline scenarios of either zero, one or two interventions. Specifically, beneficiaries of all three interventions scored 22 percent less in the household food insecurity access scale (HFIAS) compared to those who had no intervention and about 30 percent less than those who had one or two interventions (Table 4). Similarly, households receiving three interventions attained about 36 percent more household dietary diversity score (HDDS) compared to those who had no intervention, and 27 and 19 percent more than those who had one and two interventions, respectively. The results suggest that, unlike intermediate outcomes such as raising nutrition awareness, a single intervention is insufficient to achieve significant impact on the primary nutrition outcomes such as reducing food insecurity or diversifying diets.

Results from the control function approach.

Results from the control function approach (CFA) align with those from the IPWRA approach discussed above (Table 5). Residual terms for the vitamin A knowledge and household food insecurity access scale are significant, indicating endogeneity issues and justification for the use of the CFA to correct for this.

Table 5
Regression results from the control function estimation.

Variables	Intermediate outcomes		Primary outcomes	
	Vitamin A knowledge	**Nutrition knowledge**	**HFIAS**	**HDDS**
Number of interventions	0.394***	0.296*	0.0677	0.478***
	(0.0869)	(0.178)	(0.309)	(0.172)
Household head gender	0.998***	−1.717***	1.253	−0.0468
	(0.359)	(0.576)	(0.865)	(0.330)
Household head education	0.0115	0.352***	−0.388***	0.163***
	(0.0271)	(0.0666)	(0.0867)	(0.0403)
Household head age	0.0203**	−0.0208	0.0473*	0.0315**
	(0.00947)	(0.0188)	(0.0264)	(0.0131)
Household size	0.0156	0.0134	0.748***	−0.172*
	(0.053)	(0.114)	(0.175)	(0.097)
Asset index	−0.114*	−0.00515	−1.120***	−0.112
	(0.0657)	(0.171)	(0.229)	(0.118)
Distance to water source (walking minutes)	0.00310	−0.00203	0.0181**	−0.0117***
	(0.00214)	(0.00483)	(0.00743)	(0.00374)
Access to off-farm income	−0.0431	0.437	−1.115	−0.00301
	(0.283)	(0.587)	(0.736)	(0.465)
Household grew sweet potato in the last 3 years	−0.263	−0.249	−1.383*	0.435
	(0.364)	(0.607)	(0.794)	(0.383)
Children < 5 years of age	−0.397	4.065***	−1.037*	−0.278
	(0.277)	(0.498)	(0.570)	(0.254)
Makueni county	−0.662**	−0.214	−2.260***	−2.011***
	(0.301)	(0.611)	(0.821)	(0.393)
Garissa county	1.047	0.282	−1.904	2.242***
	(0.973)	(1.431)	(1.844)	(0.805)
Residual	−2.035*	−1.085	−5.153***	−0.985
	(1.047)	(1.385)	(1.942)	(0.880)
Observations	636	636	636	636

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

The greater the number of interventions to which a beneficiary is exposed, the higher the vitamin A and nutrition knowledge, and household dietary diversity. Other results show that male household heads had higher vitamin A knowledge, while more educated ones had higher nutrition knowledge and higher primary nutrition outcomes (HDDS and HFIAS). Larger households are disadvantaged in terms of both primary nutrition outcomes, while having a high asset index is associated with lower household food insecurity.

Intervention type and nutrition outcomes.

Using Epanechnikov kernel functions, we further compared nutrition outcomes (HDDS) under different combinations of interventions. We combined the HBT and HLC treatments into a composite variable for demand-side interventions and use OFSP vine provision (OVP) as the supply-side indicator variable. Fig. 2 shows the results of these comparisons.

[a] Dietary diversity for households that received OVP as the only intervention compared to those that received either HBT and/or HLC (nutrition awareness) interventions but no OVP. [b] Households that received OVP only versus those that received OVP and nutrition awareness interventions [c] Households that received nutrition awareness interventions only compared to those that received these interventions and OVP [d] Households that received OVP only, compared to those that received nutrition awareness interventions only, and those that received both these interventions.

The results indicate that, across all the various comparisons, households that were targeted with both demand- and supply- side interventions achieved higher dietary diversity compared to their counterparts (Fig. 2b and 2c). Fig. 2a further shows that supply-side interventions dominate demand-side interventions alone in enhancing nutrition outcomes. Lastly, Fig. 2d shows that interventions that combine both demand- and supply-side enablers are far more likely to lead to better nutrition outcomes, compared to either of these in isolation. In the case where only either of these is implemented, supply-side enablers, such as enhancing seed (vine) accessibility, achieve a greater impact in terms of improving outcomes compared to demand-side interventions such as BCC.

5. Conclusion and policy implications

With the increasing frequency of climate-related shocks, the sustainability of humanitarian programming in the most affected regions is becoming more pertinent. Interventions that enhance resilience in regions such as the ASALs both support livelihoods and enable them to recover from cyclical shocks. If cost-effective, such interventions may lower the burden on public and humanitarian partner budgets. Although integrated biofortification interventions have the potential to address food and nutrition insecurity among vulnerable populations, their application in humanitarian assistance is nascent. This study aimed to provide evidence on the impacts of NSA interventions aimed at promoting utilization of Vitamin A-biofortified orange-fleshed sweet potato in select ASAL counties of Kenya. The short growing period of OFSP makes it a potential commodity to enhance sustainability in the humanitarian assistance efforts in these regions.

The study finds positive impacts of biofortification-based NSA interventions on household nutrition outcomes. Interventions that address both demand- and supply- side enablers to biofortification uptake have the highest impact on household nutrition outcomes, while those that focus on either of these enablers in isolation achieve modest outcomes. Comparatively, we find that supply-side interventions (e.g., enhancing accessibility of OFSP vines) lead to higher dietary diversity compared to demand-side interventions (e.g., enhancing nutrition awareness). These results lead to our conclusion that the inclusion of biofortification, using technologies resilient to harsh weather conditions, is a viable NSA

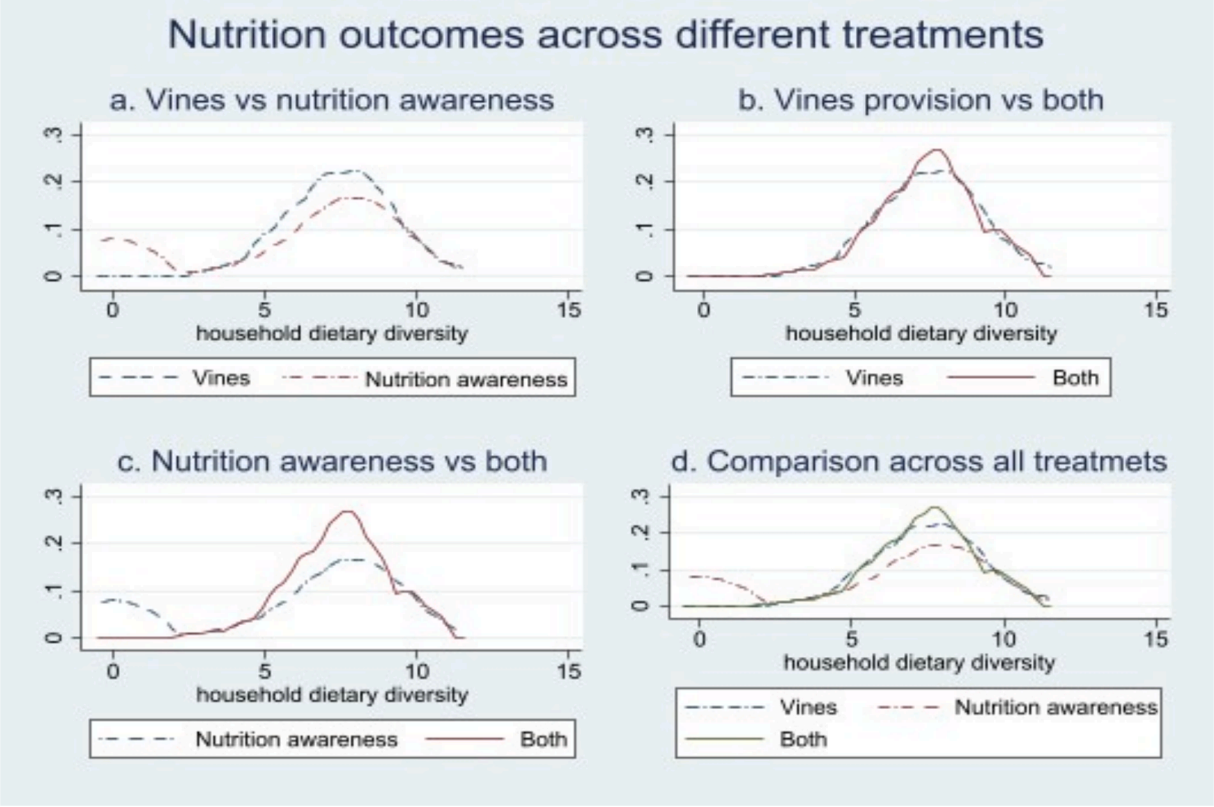

Fig. 2. Comparison of household dietary diversity scores across various nutrition interventions.

response to humanitarian needs in arid and semi-arid regions. Such interventions should focus on disentangling both demand- and supply-side enablers to uptake, with an emphasis on the latter for high impact. This may include supporting households' own production of nutritious foods, deepening market support for accessibility and affordability of such foods, and value chain investments in processing and storage to address short shelf-life and seasonality in production.

CRediT authorship contribution statement

Chalmers K. Mulwa: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Fredrick Grant:** Writing – original draft, Conceptualization. **Marcel Gatto:** Writing – review & editing. **Mukani Moyo:** Writing – review & editing, Conceptualization. **Dorcas Amunga:** Writing – review & editing, Formal analysis. **Norman Kwikiriza:** Writing – review & editing, Investigation. **Jack Malit:** Writing – review & editing, Formal analysis. **Julius J. Okello:** Writing – review & editing. **Joyce Maru:** Writing – review & editing. **Hugo Campos:** Writing – review & editing, Funding acquisition. **Simon Heck:** Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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