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Introduction of β-Carotene–Rich Orange Sweet Potato in Rural Uganda Resulted in Increased Vitamin A Intakes among Children and Women and Improved Vitamin A Status among Children[1–3]

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Abstract

Vitamin A deficiency (VAD) persists in Uganda and the consumption of β-carotene–rich orange sweet potato (OSP) may help to alleviate it. Two large-scale, 2-y intervention programs were implemented among Ugandan farmer households to promote the production and consumption of OSP. The programs differed in their inputs during year 2, with one being more intensive (IP) and the other being reduced (RP). A randomized, controlled effectiveness study compared the impact of the IP and RP with a control on OSP and vitamin A intakes among children aged 6–35 mo (n = 265) and 3–5 y (n = 578), and women (n = 573), and IP compared with control on vitamin A status of 3- to 5-y-old children (n = 891) and women (n = 939) with serum retinol <1.05 μmol/L at baseline. The net OSP intake increased in both the IP and RP groups (P < 0.01), accounting for 44–60% of vitamin A intake at follow-up. The prevalence of inadequate vitamin A intake was reduced in the IP and RP groups compared with controls among children 6–35 mo of age (>30 percentage points) and women (>25 percentage points) (P < 0.01), with no differences between the IP and RP groups of children (P = 0.75) or women (P = 0.17). There was a 9.5 percentage point reduction in prevalence of serum retinol <1.05 μmol/L for children with complete data on confounding factors (n = 396; P < 0.05). At follow-up, vitamin A intake from OSP was positively associated with vitamin A status (P < 0.05). Introduction of OSP to Ugandan farming households increased vitamin A intakes among children and women and was associated with improved vitamin A status among children. J. Nutr. 142: 1871–1880, 2012.

Introduction

Vitamin A deficiency (VAD)[11] continues to be a public health concern in developing countries among children and women of childbearing age (1) and is estimated to account for >600,000 deaths each year globally among children <5 y of age (2). It is associated with increased risk of mortality and severity of diarrhea among children (3), blindness due to xerophthalmia (4), anemia (5), and night blindness among pregnant women (6). Although large-scale programs are not yet in place, biofortification of staple foods with provitamin A through conventional breeding is projected to be a cost-effective strategy to reduce VAD in at-risk rural populations (7).

In Africa, the estimated prevalence of VAD (serum retinol <0.70 μmol/L) is 42% among children 6–59 mo of age and 14% among pregnant women (1). Uganda is among the African countries reported to be at high risk (1), with the prevalence of VAD among children and women at 28% and 23%, respectively, in 2000–2001 (8).

In Uganda, high-dose vitamin A capsule distribution and fortification of vegetable oil and fats have been implemented to address VAD. The 2008 coverage rates for vitamin A supple-

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[3] Supplemental Tables 1 and 2 and Supplemental Figure 1 are available from the "Online Supporting Material" link in the online posting of this article and from the same link in the online table of contents at http://jn.nutrition.org.
[11] Abbreviations used: EAR, Estimated Average Requirement; IP, intensive program; OSP, orange sweet potato; RAE, retinol activity equivalent; RP, reduced program; VAD, vitamin A deficiency.
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mentation were 67%, indicating one-third of children did not receive at least one high-dose capsule in the last year (9). For some individuals, even 2 vitamin A capsules per year may not be enough to maintain adequate vitamin A stores between doses (10). The impact of vitamin A-fortified vegetable oil on vitamin A status has not, to our knowledge, been assessed in this population. A recent simulation of dietary intake data from Uganda indicated that even if all vegetable oil consumed was fortified with vitamin A to current levels, it would reduce, but not eliminate, inadequate vitamin A intake in the population (11).

Sweet potato is a major staple food in some countries, including Uganda (12), but current varieties are white or pale yellow and contain no or relatively little provitamin A carotenoids (13). In contrast, orange-fleshed varieties of sweet potato (OSP) can contain large amounts of β-carotene. Consumption of OSP has been shown to improve vitamin A status in controlled efficacy trials (14–16). A small-scale effectiveness study that introduced OSP for home production and consumption in Mozambique also reported decreased prevalence of VAD among children (17). Despite this compelling evidence, research and experience are still required to determine the effectiveness of this type of intervention when implemented on a large scale. Further, applied research is required to evaluate the intensity of intervention necessary to successfully introduce a new crop such as OSP and ultimately to assess the cost-effectiveness of delivery strategies.

We undertook a randomized, controlled, cluster-design effectiveness study of the impact of introducing β-carotene–rich OSP to rural farm households in Central and Eastern Uganda on the adequacy of vitamin A intake and status among children and women. We also hypothesized that an intervention providing extension services in the form of complementary agricultural and nutrition trainings over a 2-y period would have a greater impact than an intervention with only 1 y of extension and training support. Therefore, an additional objective was to compare the effectiveness of 2 intervention models, which differed in the duration of direct community contact.

Participants and Methods

Intervention implementation design. A 2-y intervention to introduce household-level cultivation of OSP was implemented in 2007–2009 in 3 districts of Eastern and Central Uganda (Mukono, Bukedea, and Kamuli) selected for the relative importance of sweet potato production and consumption. This was a large-scale intervention, reaching >10,000 households from 381 farmer groups, designed to learn lessons about how best to scale-up. The unit of intervention was the existing community-based farmer groups that included 25–30 members from 1–2 villages. Two-thirds of the farmer group members were women. Local, nongovernmental organizations (Volunteer Efforts for Development Concerns and Farming for Food and Development Program-Eastern Uganda) implemented the intervention, while project implementation staff provided overall coordination.

The 3 intervention components, agriculture, demand creation/behavior change, and marketing, were delivered through training with farmer group household members as well as through broader, area-wide activities and promotions. The agricultural component supported the distribution of 20 kg free OSP vines per household as planting material and provided farmer groups training on improved production practices, such as avoidance of pests and diseases and vine conservation. The demand creation/behavior change component included education on child and maternal health and nutrition topics targeted to women in the participating farmer group households and a broader campaign for the general public to raise awareness of the benefits of OSP as a source of vitamin A through community drama, field day events, and radio spots and programs. The marketing component included provision of information on market opportunities at the farmer group level as well as an area-wide recruitment and training of local OSP traders, urban and rural market development for the sale of OSP, and the establishment of distinct market stalls selling and providing information on OSP.

To implement the study, a pyramidal structure of extension was used whereby, in year 1, a group of project-employed extensionists (n = 11) trained and then assisted community-level volunteer promoters (n = 282 pairs of agriculture/marketing promoters and behavior change promoters). Each pair of promoters trained members of one farmer group, thus reaching 7500 members in year 1.

Two intervention models were used: an intensive program (IP) and a reduced program (RP), which differed primarily in duration of exposure to farmer group-level inputs (**Supplemental Table 1**). Both programs provided the same intervention inputs during year 1. In year 2, the farmer group-level training sessions in agriculture and marketing opportunities and education sessions in nutrition and health continued only in the IP groups, while the area wide-level marketing and demand creation/behavior change inputs continued in both IP and RP. Assignment to IP, RP, or control was done at the farmer group level. Potential exposure to area-wide activities, such as radio programs and access to any local OSP market stalls, did not differ.

Effectiveness study design. The interventions' impact on nutritional outcomes was evaluated by a separate research team using a cluster randomized, controlled, effectiveness study design, with stratification at the district level and farmer groups serving as sample clusters (**Supplemental Fig. 1**). A sample of 84 farmer groups was selected for the study prior to the intervention. Farmer groups were randomly assigned to the IP, RP, or control groups within district strata. To minimize contamination, farmer groups <5 km apart were grouped into a single cluster and then one farmer group was randomly selected from such clusters for inclusion in the study. In some cases, membership in farmer groups was augmented to ensure the number of members with children <6 y of age met sample size requirements. The nutrition impact study included an assessment of dietary intakes at baseline and after 2 y of the intervention in all 3 study groups, and of vitamin A status in the IP and control groups only. In each survey round, data collection occurred during the sweet potato harvest season. The primary outcomes were changes in OSP intake and vitamin A intake and change in serum retinol among participants with serum retinol <1.05 μmol/L at baseline. This study was approved by the ethical review boards of the Makerere University Medical School, the Uganda National Council of Science and Technology, and the International Food Policy Research Institute.

Participants. Three age groups were included: children 6–35 mo of age, children 3–5 y of age, and women. Household samples were drawn from among all households in the sampled farmer group with at least one child aged 3–5 y; if more than one child in that age range was present in the household, then one was selected at random for inclusion in the study. The mother of this child, if available, or otherwise the child's primary female caregiver was selected for inclusion in the sample of women in the study. Children 3–5 y of age and women were followed longitudinally whenever possible. However, a limited number of children and women not interviewed at baseline, but who were eligible, were added to the sample at follow-up. Two cross-sectional groups of children 6–35 mo of age were surveyed at baseline and follow-up. The latter were included to assess the impact of the intervention on young child feeding. Children 6–35 mo of age were included in the dietary assessment component only and recruited from the same households as the 3- to 5-y-old children or from other farmer group households as needed to meet sample size requirements. Informed consent was obtained from the children's caregivers.

Dietary intake assessment. The interactive, 24-h recall method was used to obtain detailed information on food intakes (18). Interviewers were carefully trained and closely supervised throughout data collection. Prior to the dietary recall interview, female caregivers were trained on the purpose and methods of the interview. The interview was conducted in the household using visual aids to assist in estimating portion sizes of

foods consumed. Data collection forms were reviewed daily by a team leader, aberrancies were clarified, and the field supervisor reviewed dietary records and assured standardization of procedures across field teams. Energy and nutrient intakes were computed from a food composition table compiled for this project (19), consisting of published values primarily from the USDA (20). The analysis accounted for nutrient losses during cooking for all cooked food items.

One day of dietary intake data was obtained for all individuals, and a second day of data was obtained on a nonconsecutive day for a randomly selected subset of individuals to enable estimation of within-person variability (21). The distribution of usual vitamin A intakes was determined after adjusting intakes for within-person variability using the Iowa State University method (22) and PC-SIDE (version 1.0, Iowa State University). The Best Linear Unbiased Predictors (23) were derived and used to make group comparisons of usual vitamin A intakes (21). The prevalence of inadequate vitamin A intakes was approximated using the Estimated Average Requirement (EAR) cut-point method (21), applying EAR of 210, 275, 500, and 900 μg retinol activity equivalent (RAE) for children 1–3 and 4–8 y old, nonpregnant/nonlactating women, and lactating women, respectively (24). Data were examined for implausibly high intakes and these were removed as necessary for this analysis. For these estimates, infants <12 mo of age and those still breastfed were excluded, because EAR were not available. Data for pregnant women were combined with nonpregnant/nonlactating women. To facilitate the presentation of the prevalence of inadequate intakes, usual intakes for lactating women were rescaled to the daily intakes of the nonlactating women using a factor proportionate to the difference in EAR (i.e., 900/500 μg RAE); a similar method was used for the children 3–5 y at baseline, because they straddled 2 EAR age groups.

β-Carotene content of OSP. Four different OSP varieties were released in the intervention. Ejumula, Kakamega (SPK004), Vita (SPK004/6), and Kabode (SPK004/6/6) contained 9062, 4071, 9655, and 7460 μg β-carotene/100 g raw, fresh weight, respectively (25). Retention of β-carotene after cooking was accounted for (25). The proportion of each OSP variety grown varied by district. Therefore, to determine vitamin A intakes from OSP, we calculated a district-specific mean content by combining the all-*trans*-β-carotene content of each OSP variety with district-level data on total area planted by variety (hectare) at follow-up and controlled data on yields (kg/hectare) by variety. The β-carotene and vitamin A contents of fresh, raw OSP applied to dietary intake data from Kamuli, Bukedea, and Mukono districts were 7.33, 6.43, and 7.91 mg β-carotene/100 g, respectively, and 611, 536, and 659 μg vitamin A RAE/100 g (assuming 12:1 retinol equivalency), respectively.

Blood collection. Venous blood samples were collected from children 3–5 y at baseline and women by trained phlebotomists following standard sterile procedures. Blood tubes were immediately wrapped in aluminum foil to protect them from light, stored in a cooler box under refrigerated temperatures, and transported daily to a district-level facility, where serum was separated by centrifugation (2000–3000 $\times$ *g* for 10–15 min) and stored in cryotubes under liquid nitrogen. Samples were transported weekly to Kampala for storage. Cryotubes designated for retinol analysis were air-shipped under dry ice to Craft Technologies.

Biochemical analyses. AGP and CRP concentrations were determined in the Biochemistry Department of Makerere University by commercial Radial Immuno Diffusion assay kits following the manufacturer's protocol (Kent Laboratories). The diameters of precipitin rings were read using a digital RID plate reader (The Binding Site). Inter-run CV for AGP and CRP determinations were 2.1–8.5% and 9.1–23.1%, respectively. Serum AGP $\geq$1.0 g/L and CRP $\geq$5.0 mg/L were taken to indicate presence of infection (26).

The serum retinol concentration was determined by normal-phase HPLC (27). Standards for retinol were prepared and checked daily. Internal serum controls calibrated against a standard reference material (NIST SRM 968c) were used for quality assurance. The inter-run CV of the internal controls was 2.5–5.3% (n = 250 analyses over 16 runs). A pooled control sample prepared in Uganda at follow-up had an inter-run CV of 8.4% (n = 43 analyses over 8 runs). During shipment of baseline serum samples, some cryotubes (i.e., children 3–5 y at baseline, 22% and women, 3%) were exposed to thawing, which was likely short term, because other samples arrived frozen or semi-frozen. We used regression analysis to verify the quality of samples for children; after controlling for district, sex, elevated CRP and AGP, and AGP $\times$ CRP, sample state on arrival was not found to be a significant factor among children (coefficient = 0.005; P = 0.92) and all baseline samples were maintained. Due to the small number of the women's samples affected and the smaller number of those with baseline retinol <1.05 μmol/L (n = 95), the thawed samples were retained and final models were estimated with and without controlling for thawing at baseline. Baseline serum retinol was adjusted for 3 stages of infection based on elevated CRP and/or AGP (26).

Anthropometry. Trained anthropometrists measured body weight ($\pm$0.1 kg) of children in light clothing using electronic scales (SECA mother and child scales). Height or length (children <24 mo of age) was measured in duplicate using wooden measuring boards (Shorr Productions). Height- or length-for-age and weight-for-age Z-scores were calculated using WHO reference standards (28).

Sample size. For serum retinol, a similar study observed a mean (SD) change of 0.075 (0.17) μmol/L (17) and the intra-cluster correlation coefficient for serum retinol among children 6–59 mo of age from Central and Eastern Uganda was 0.043 (8). To minimize sample size, the impact assessment was restricted to those with infection-adjusted serum retinol <1.05 μmol/L at baseline, a level below which vitamin A status is likely to improve with increased vitamin A intake (29), and thus the likelihood of observing an impact on vitamin A status would be greater in this subset than in the whole sample. Using these data, a change of 0.044 μmol/L could be detected with 80% power and 5% level of significance with 432 children from 36 farmer groups in each of the IP and control groups. The same sample size was used for women.

For the dietary component, the SD of the change in vitamin A intake in a previous study was 400 μg RAE/d and the intra-cluster correlation coefficient was 0.218 (17). A sample of 6 children 3–5 y of age from households in the 36 farmer groups each in IP and control groups could identify a net change in vitamin A intake of 228 μg RAE/d, an amount considered biologically meaningful and representing >100% of the EAR. For cost reasons, sample size was reduced for RP households; 12 farmer groups with 12 households/group would allow us to identify a net change of 346 μg RAE/d. For the subsample of children aged 6–35 mo, sampling 3 younger children in each IP and control farmer group and 6 children in each RP farmer group would be sufficient to identify impacts of at least 277 and 408 μg RAE/d, respectively.

Data management and analyses. All data were entered using CSPro (Serpro) in duplicate by trained staff and corrected after identification of inconsistent results. Dietary data were captured using CSDietary, a CSPro-based software. Analyses were carried out using the complex survey module in Stata (StataCorp). Baseline differences among groups were tested by the Adjusted Wald test. Results were analyzed as intent-to-treat models. Treatment effects were estimated using difference-in-difference models, equivalent to Ordinary Least Squares, that determine the change in group mean outcomes from baseline to follow-up and calculate the difference in that change between 2 comparison groups. Although not deemed necessary for difference-in-difference analyses, mixed models controlling for individual random effects were also estimated to control for correlation in observations for children 3–5 y at baseline and women who appeared in both rounds; any differences in results between models are noted. The difference-in-difference results of these models are forthwith referred to as net change. Data are presented as means or percentages (SE), with SE adjusted for clustering and stratification at the district level. Although not all primary outcome variables were normally distributed, impact analyses compared group means. Impact was also tested using Box-Cox–transformed data (30), but because results did not differ, nontransformed data were presented for ease of interpretation. The impact on vitamin A status was determined, with and without covariates, for serum retinol concentration and prevalence of retinol <1.05 or <0.70 μmol/L among participants with

infection-adjusted serum retinol <1.05 μmol/L at baseline. Regression models were used to explore associations between dietary intakes and serum retinol concentration.

Results

The characteristics of children and women among study groups did not significantly differ at baseline (**Table 1**). For the longitudinal sample, the rate of attrition was 12% among women and 13% among children 3–5 y of age at baseline. For the follow-up survey, this was compensated by admitting additional eligible women and children equivalent to 15 and 2%, respectively, of the baseline sample size.

OSP intakes. At baseline, there was no significant difference in intake of total sweet potato (not shown) or OSP among study groups (**Table 2**). At follow-up, there was a significant net increase in the intake of OSP in the IP and RP groups relative to the control among all 3 age groups, but change in OSP intakes did not significantly differ between the IP and RP groups. At follow-up, the proportion of all sweet potato consumed as OSP across age groups was ≥38% in the IP group and ≥31% in the RP group, whereas in the control group, this remained at ≤4%. Total intake of sweet potato did not significantly change in the IP and RP groups, whereas the net change in intake of white and yellow varieties tended to be negative. In the IP and RP groups, intake of OSP was reported for 23–33% of children on the recall day.

Vitamin A intakes and sources. At baseline, vitamin A intakes (μg RAE/d) did not differ among study groups, except for adjusted intakes among women, where intakes were higher in the control group than in the IP or RP groups ($P < 0.05$) (**Table 3**). Impact estimates indicated a significant net increase in total, unadjusted vitamin A intakes among children 3–5 y at baseline and women in both the IP and RP groups and among children 6–35 mo in the RP group only. For the adjusted vitamin A intake distribution, a significant net positive change was observed for the IP and RP group among children 3–5 y at baseline, women, and the subset of non-breastfed children ≥12–35 mo of age. With the exception of adjusted vitamin A intakes among children 3–5 y at baseline, vitamin A intakes did not significantly differ between the IP and RP groups. When a mixed model analysis was used, net-adjusted vitamin A intake also differed between the IP and RP groups among women ($P < 0.05$). The net increases in total vitamin A intake were due to an increased β-carotene intake and vitamin A-source OSP and not to a difference in the intake of retinol or non-OSP sources (Table 3).

TABLE 1 Baseline characteristics of participants in a study of the effectiveness of an intervention to introduce OSP in rural Uganda[1]

	All	IP	RP	Control	P^2
Children 6–35 mo					
n	264	100	66	98	
Age, *mo*	20.8 ± 0.5	20.1 ± 0.8	22.1 ± 0.8	20.7 ± 0.8	0.21
Female, %	53.8 ± 3.1	53.0 ± 5.1	50.0 ± 6.0	57.1 ± 5.2	0.67
Breastfed, %	46.8 ± 3.1	53.1 ± 5.5	42.1 ± 4.0	43.2 ± 5.2	0.27
Length- or height-for-age Z-score < −2.0,[3] %	39.4 ± 3.2	35.7 ± 4.7	40.6 ± 7.3	42.3 ± 5.0	0.63
Weight-for-age Z-score < −2.0,[3] %	17.9 ± 2.6	17.0 ± 4.1	21.5 ± 5.5	16.3 ± 3.9	0.73
Children 3–5 y at baseline					
n	544	205	131	208	
Age, *mo*	51.4 ± 0.4	50.8 ± 0.6	51.0 ± 0.9	52.2 ± 0.6	0.24
Female, %	51 ± 2	57 ± 3	53 ± 5	45 ± 4	0.07
Height-for-age Z-score < −2.0,[3] %	28.3 ± 1.9	27.4 ± 3.3	30.2 ± 3.8	27.9 ± 3.3	0.85
Weight-for-age Z-score < −2.0,[3] %	9.4 ± 1.2	8.3 ± 2.0	9.2 ± 1.8	10.6 ± 2.2	0.74
Serum retinol					
n	881	435	—	446	
μmol/L	0.92 ± 0.02	0.94 ± 0.03	—	0.91 ± 0.02	0.48
<0.70 μmol/L, %	29.4 ± 2.1	28.7 ± 3.1	—	30.0 ± 3.2	0.78
<1.05 μmol/L, %	*72.2* ± 1.9	70.8 ± 2.9	—	73.5 ± 2.6	0.50
Women					
n	539	205	131	203	
Age, *y*	34.0 ± 0.5	32.8 ± 0.7	35.8 ± 1.3	33.9 ± 0.6	0.12
Pregnant, %	12.9 ± 1.5	11.4 ± 2.6	10.0 ± 2.1	16.3 ± 2.6	0.18
Lactating, %	41.8 ± 2.1	47.8 ± 3.1	34.6 ± 6.2	40.4 ± 2.7	0.11
Serum retinol					
n	899	450	—	449	
μmol/L	1.75 ± 0.04	1.79 ± 0.06	—	1.71 ± 0.04	0.28
<0.70 μmol/L, %	1.7 ± 0.04	1.3 ± 0.5	—	2.0 ± 0.6	0.39
<1.05 μmol/L, %	11.2 ± 1.1	9.1 ± 1.5	—	13.4 ± 1.7	0.07

[1] Data are means or prevalences ± SE. IP, intensive program; OSP, orange sweet potato; RP, reduced program.
[2] *P* values report results of Adjusted Wald Tests of differences in group means and prevalences, correcting for survey design. Data are presented for 2 intervention models and a control group, where farmer group-level intervention components continued for 2 y in IP, 1 y in RP, and were absent in the control group.
[3] For length-for-age, height-for-age, and weight-for-age Z-scores, the number of observations are: children 6–35 mo, 100, 65, and 98; children 3–5 y at baseline: 205, 130, and 208 for IP, RP, and control groups, respectively.

TABLE 2 Net change in mean sweet potato intakes by type following an intervention to introduce OSP in rural Uganda[1]

	Baseline mean			Follow-up mean			Net change[2]		
	IP	RP	Control	IP	RP	Control	IP − control	RP − control	IP − RP
				Sweet potato intakes, g/d					
Children 6–35 mo[3]									
n	98	57	95	104	62	105	402	319	321
White	43 ± 10[b]	9 ± 4[a]	24 ± 6[b]	27 ± 8	19 ± 7	39 ± 8	−31 ± 13*	−4 ± 12	−26 ± 12*
Yellow	28 ± 7	28 ± 8	47 ± 10	18 ± 4	52 ± 18	77 ± 18	−39 ± 18*	−6 ± 23	−33 ± 18
Orange	3 ± 1	2 ± 2	2 ± 1	53 ± 12	39 ± 11	1 ± 2	51 ± 13**	37 ± 13**	14 ± 18
Children 3–5 y at baseline									
n	205	131	208	189	117	175	777	631	642
White	72 ± 12[b]	37 ± 9[a]	61 ± 13[a,b]	85 ± 18	89 ± 18	141 ± 24	−66 ± 27*	−28 ± 29	−38 ± 24
Yellow	72 ± 13	73 ± 15	100 ± 15	76 ± 10	124 ± 23	136 ± 21	−32 ± 25	14 ± 34	−46 ± 31
Orange	8 ± 4	1 ± 1	5 ± 3	101 ± 16	129 ± 29	13 ± 4	85 ± 17**	120 ± 29**	−35 ± 34
Women									
n	205	131	203	212	130	213	833	677	678
White	142 ± 29[b]	51 ± 13[a]	112 ± 20[b]	117 ± 23	112 ± 26	207 ± 33	−120 ± 39**	−34 ± 35	−86 ± 34*
Yellow	143 ± 30	120 ± 18	175 ± 29	129 ± 21	155 ± 21	222 ± 42	−60 ± 51	−11 ± 44	−49 ± 41
Orange	8 ± 6	2 ± 2	1 ± 1	167 ± 33	119 ± 25	6 ± 3	153 ± 35**	111 ± 26**	42 ± 45

[1] Baseline and follow-up data are means ± SE, adjusted for the cluster (farmer group) and stratification (district) design of the survey. Data are presented for 2 intervention program models and a control group, where farmer group-level intervention components continued for 2 y in IP, 1 y in RP, and were absent in the control. Children 3–5 y at baseline and women were followed longitudinally, with exceptions due to limited attrition and entry into the sample as an eligible participant at follow-up. All individuals in these groups were included in estimating means in each round. Children 6–35 mo were sampled from 2 cross-sectional groups at baseline and follow-up. Labeled baseline means without a common letter differ, $P < 0.05$. IP, intensive program; OSP, orange sweet potato; RP, reduced program.

[2] Net change is the difference-in-difference measure of impact. It is estimated by taking the change in group mean outcomes from baseline to follow-up and calculating the difference in that change between the 2 treatment/control groups. Net change was estimated in a model equivalent to Ordinary Least Squares. To control for correlation in observations for children 3–5 y at baseline and women who appeared in both rounds, net change was also estimated in mixed models controlling for individual random effects; significance levels did not differ between the 2 models. Sample sizes for net change represent the total number of observations on the outcome used to measure the difference in changes over time between groups.

[3] Means and impact estimates for children 6–35 mo of age are conditioned on breastfeeding status. Test statistics are *t* statistics: $*P < 0.05$, $**P < 0.01$.

Large and significant net decreases were observed in the prevalence of inadequate vitamin A intake among 12- to 35-mo-old children and women in both the IP and RP groups ($P < 0.05$) but not among children 3–5 y at baseline (**Fig. 1**).

At baseline, OSP accounted for only 2–6% of total vitamin A intakes across age groups. Other sources of vitamin A at baseline were yellow sweet potato (23–40%), vegetables (25–34%), vegetable oils (9–12%), meats and fish (7–13%), dairy and eggs (3–9%), and fruits (3–5%). However, at follow-up, OSP contributed 44–60% of total vitamin A intakes in the IP and RP groups and 5–11% in the control group.

Vitamin A status and infection. Based on the presence of elevated serum CRP and/or AGP, 79% of children 3–5 y a baseline and 41% of women were in some stage of infection at the time of blood sampling (**Supplemental Table 2**) and this did not differ between the IP and control groups at baseline or follow-up.

The retinol concentration and prevalence of low serum retinol did not differ between the IP and control groups at baseline (Table 1). Applying the correction factors for infection resulted in at least a one-third reduction in the prevalence of retinol <0.70 μmol/L among children 3–5 y at baseline (Supplemental Table 2). For women, the prevalence of retinol <0.70 μmol/L was low (≤2%) even before correcting for infection.

Impact on vitamin A status. As per the study design, the impact on serum retinol was evaluated only among children and women in the control and IP groups with infection-adjusted serum retinol <1.05 μmol/L at baseline (**Table 4**). For children 3–5 y at baseline, the impact analysis is presented for 2 models. First, among the sample of children with complete data for serum retinol, AGP, and CRP ($n = 472$), there was no significant impact of the intervention on serum retinol concentration or the prevalence of retinol <0.70 μmol/L when all children in this sample were considered, although the 7.6-percentage point reduction in the prevalence of children with retinol <1.05 μmol/L in IP approached significance ($P = 0.09$).

A second analysis included only children with complete data on important covariates, including age in months and receipt of a deworming pill or vitamin A supplement in the last 12 mo ($n = 396$). In this subset, IP was associated with a significant 9.5-percentage point reduction in the prevalence of serum retinol <1.05 μmol/L ($P < 0.05$) (Table 4). Age and receipt of a deworming pill were among the significant covariates. Among women, there was only a small number with baseline-adjusted serum retinol <1.05 μmol/L ($n = 95$) and no impact was observed on serum retinol concentration or prevalence of retinol <1.05 μmol/L (Table 4).

When considering only follow-up data, in the subset of children 3–5 y at baseline with baseline-adjusted serum retinol <1.05 μmol/L and dietary intake data, vitamin A intake from OSP was significantly and positively associated with serum retinol and with a lower prevalence of retinol <1.05 and <0.70 μmol/L (**Table 5**). In the similarly defined subset of women, vitamin A intake from OSP was significantly associated with a lower prevalence of serum retinol <1.05 μmol/L, but not with serum retinol concentration.

Discussion

This large-scale intervention to introduce OSP to rural Ugandan communities resulted in a significant increase in the dietary

TABLE 3 Net change in mean vitamin A intake by source following an intervention to introduce OSP in rural Uganda[1]

	Baseline			Follow-up			Net change[2]		
	IP	RP	Control	IP	RP	Control	IP − Control	RP − Control	IP − RP
Children 6–35 mo[3]									
n	98	57	95	104	62	105	402	319	321
Vitamin A RAE,[4] *μg/d*									
Unadjusted	315 ± 49	242 ± 39	315 ± 59	443 ± 61	425 ± 70	279 ± 40	163 ± 104	219 ± 105*	−56 ± 113
Adjusted [5]	266 ± 23	230 ± 24	303 ± 40	518 ± 21	414 ± 16	258 ± 20	297 ± 51**	229 ± 52**	68 ± 43
OSP source	15 ± 7	6 ± 5	11 ± 8	265 ± 59	197 ± 59	6 ± 10	256 ± 63**	197 ± 65**	59 ± 90
Non-OSP source	301 ± 49	236 ± 40	304 ± 58	178 ± 20	227 ± 35	274 ± 38	−92 ± 85	22 ± 85	−114 ± 78
Preformed vitamin A	53 ± 22	33 ± 11	74 ± 50	36 ± 4	32 ± 4	25 ± 5	31 ± 56	47 ± 54	−16 ± 26
β-Carotene, *mg/d*	2.22 ± 0.36	1.78 ± 0.37	2.12 ± 0.33	4.09 ± 0.71	4.09 ± 0.80	2.34 ± 0.44	1.65 ± 0.89	2.09 ± 1.01*	−0.44 ± 1.21
Children 3–5 y at baseline									
n	205	131	208	189	117	175	777	631	642
Vitamin A RAE[4], *μg/d*									
Unadjusted	542 ± 62	434 ± 56	550 ± 76	869 ± 88	1110 ± 200	581 ± 55	296 ± 139*	649 ± 210**	−353 ± 217
Adjusted[5]	482 ± 21	487 ± 16	471 ± 27	780 ± 30	949 ± 80	563 ± 14	206 ± 37**	370 ± 74**	−164 ± 78*
OSP source	43 ± 18[b]	4 ± 4[a]	39 ± 19[a,b]	499 ± 81	643 ± 152	66 ± 20	429 ± 88**	613 ± 155**	−184 ± 180
Non-OSP source	499 ± 61	430 ± 57	510 ± 75	370 ± 26	471 ± 62	515 ± 50	−134 ± 108	36 ± 111	−170 ± 90
Preformed vitamin A	113 ± 52	23 ± 4	112 ± 65	44 ± 15	28 ± 4	46 ± 23	−4 ± 90	71 ± 71	−75 ± 55
β-Carotene, *mg/d*	3.92 ± 0.44	3.63 ± 0.51	4.19 ± 0.48	8.88 ± 1.02	11.9 ± 2.3	4.90 ± 0.57	4.24 ± 1.16**	7.60 ± 2.25**	−3.35 ± 2.44
Women									
n	205	131	203	212	130	213	833	677	678
Vitamin A RAE[4], *μg/d*									
Unadjusted	692 ± 73	683 ± 87	855 ± 120	1390 ± 170	1220 ± 170	762 ± 90	788 ± 222**	632 ± 192**	156 ± 221
Adjusted[5]	632 ± 24[a]	661 ± 23[a]	793 ± 34[b]	1270 ± 60	1130 ± 80	667 ± 32	763 ± 69**	591 ± 76**	172 ± 89
OSP source	36 ± 18	5 ± 5	3 ± 2	810 ± 161	588 ± 127	33 ± 17	744 ± 168**	553 ± 130**	191 ± 218
Non-OSP source	656 ± 73	678 ± 88	852 ± 120	578 ± 48	635 ± 73	729 ± 83	44 ± 154	80 ± 153	−35 ± 101
Preformed vitamin A	43 ± 18	35 ± 9	156 ± 88	66 ± 20	51 ± 8	40 ± 4	139 ± 93	131 ± 89	8 ± 30
β-Carotene, *mg/d*	6.18 ± 0.79	5.77 ± 0.83	6.65 ± 0.92	14.3 ± 2.1	12.4 ± 1.9	6.87 ± 1.04	7.87 ± 2.33**	6.41 ± 1.81**	1.46 ± 2.63

[1] Baseline and follow-up data are means ± SE, adjusted for the cluster (farmer group) and stratification (district) design of the survey. Data are presented for 2 intervention program models and a control group, where farmer group-level intervention components continued for 2 y in IP, 1 y in RP, and were absent in the control. Children 3–5 y at baseline and women were followed longitudinally, with exceptions due to limited attrition and entry into the sample as an eligible participant at follow-up. All individuals in these groups were included in estimating means in each round. Children 6–35 mo were sampled from 2 cross-sectional groups at baseline and follow-up. Labeled baseline means without a common letter differ, $P < 0.05$. IP, intensive program; OSP, orange sweet potato; RAE, retinol activity equivalent; RP, reduced program.

[2] Net change is the difference-in-difference measure of impact. It is estimated by taking the change in group mean outcomes from baseline to follow-up and calculating the difference in that change between the 2 treatment/control groups. Net change was estimated in a model equivalent to Ordinary Least Squares. To control for correlation in observations for children 3–5 y at baseline and women who appeared in both rounds, net change was also estimated in mixed models controlling for individual random effects. Significance levels only differed for women, where net change for adjusted vitamin A RAE intake for IP − RP was significant ($P < 0.05$) in the mixed model analysis. Sample sizes for net change represent the total number of observations on the outcome used to measure the difference in changes over time between groups.

[3] Means and impact estimates for children 6–35 mo of age are conditioned on breastfeeding status. Test statistics are *t* statistics: *$P < 0.05$, **$P < 0.01$.

[4] μg Vitamin A RAE was calculated using the formula: [μg preformed vitamin A (retinol)/1] + (μg *β*-carotene/12) + (μg *α*-carotene/24) + (μg *β*-cryptoxanthin/24).

[5] Adjusted mean vitamin A intakes from a distribution corrected for intra-individual variation based on a second day of dietary recall data in a subset of individuals. All other intakes presented are from a single day of dietary recall data per individual. For the group of children 6–35 mo of age, children <12 mo of age and breast-fed children were excluded from the adjusted measure, whereas for children 3–5 y at baseline and women, a limited number of observations was excluded due to implausibly high intakes in the follow-up survey (Supplemental Fig. 1).

intake of OSP among children and women in farmer group member households. This resulted in a substantial increase in total vitamin A intake from *β*-carotene in all 3 age groups and a significant decrease in the prevalence of inadequate vitamin A intakes among non-breastfed 12- to 35-mo-old children and women, with similar outcomes in both treatment groups. Although no change in mean serum retinol was observed among women, among children with low serum retinol at baseline, there was a positive association between vitamin A intakes from OSP and vitamin A status at follow-up and a positive intervention impact on vitamin A status among children with complete data on important control variables.

This large-scale effectiveness study indicates that, in a population where sweet potato is a major staple food, rural farming households were willing to substitute one-third of their usual sweet potato intake with OSP. Changing the color of a staple food from white to orange could have been met with resistance, but OSP was widely produced and consumed at the household level after 2 y. The acceptability of OSP in this study is consistent with the results of consumer acceptance studies of OSP in this region (31,32). At follow-up, OSP provided 44–60% of total vitamin A intakes in the IP and RP groups. This level of substitution was sufficient to increase the vitamin A intakes by all age groups by >100% of the age-specific EAR (24), representing a substantial increase.

Our hypothesis that the longer period of direct contact between extensionists and volunteer promoters and farmer group members in the IP group would result in greater adoption and intake of OSP was not substantiated by the results. This is an important finding with regard to the cost-effectiveness of a large-scale program, because the costs of extended community contact are high and may not translate into a greater impact.

This population was characterized by a high prevalence of inadequate vitamin A intake at baseline, which was significantly reduced by the intervention among the non-breastfed children 12–35 mo of age from nearly 50% at baseline to only 12% at

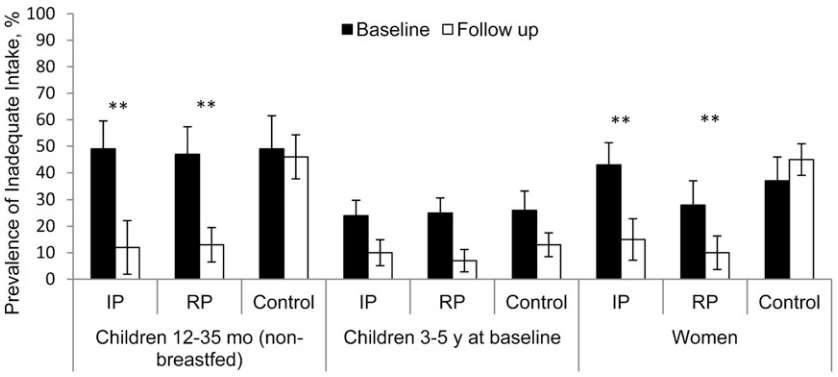

FIGURE 1 Effect of an intervention to introduce OSP in rural Uganda on the prevalence of inadequate vitamin A intakes among children and women. Data are mean prevalence of inadequate intakes of vitamin A RAE at baseline and follow-up for cross-sectional studies of non-breastfed children 12–35 mo of age and longitudinal cohorts of children 3–5 y of age at baseline and women. Data are presented for 2 intervention models, where farmer group-level intervention components continued for 2 y in the IP group and 1 y in the RP group, while area wide-level intervention components continued for 2 y in both the IP and RP groups. For IP, RP, and control at baseline, the number of observations are: non-breastfed children 12–35 mo, 90, 61, and 86; children 3–5 y at baseline, 218, 143, and 219; and women, 219, 143, and 214, respectively. For IP, RP, and control groups at follow-up, the number of observations are: non-breastfed children 12–35 mo, 96, 63, and 93; children 3–5 y at baseline, 194, 124, and 180; and women, 220, 146, and 219, respectively. Error bars indicate 95% CI. Comparisons are for net change, estimated by taking the change in group mean outcomes from baseline to follow-up and calculating the difference in that change between the IP or RP and control groups between baseline and follow-up: $^{**}P < 0.01$. IP, intensive program; OSP, orange sweet potato; RAE, retinol activity equivalent; RP, reduced program.

follow up. This is an important finding, because young children who have recently stopped breastfeeding are at elevated risk of VAD, as breast milk is the primary source of vitamin A (33) and the vitamin A requirements for this group are still relatively high. A similar impact was observed among women. However, the large increase in vitamin A intakes among children 3–5 y at baseline did not translate to a significant reduction in the prevalence of inadequate intakes. At baseline, the prevalence of inadequacy was lower in this age group than in the other groups (i.e., 24–27% vs. 28–49%), declining to 7–13% across all groups. Thus, most children at follow-up, including in the control group, had adequate vitamin A intakes relative to the EAR. This may be attributed to age-related increases in food intake, resulting in higher mean vitamin A intakes at follow-up across all groups, whereas the theoretical vitamin A dietary requirements increased only for children who crossed over from one EAR age category to the next (i.e., from 1–3 y to 4–8 y) between baseline and follow-up. As a result, the age-related increase in mean vitamin A intakes exceeded the increase in theoretical requirements, resulting in a lower prevalence of inadequate intakes.

We did not find an overall impact of the intervention on serum retinol or prevalence of VAD among women. VAD was unexpectedly very low in this population of women (2%) and hence the number of women for whom impact of the intervention was determined was small, resulting in inadequate statistical power. Among children 3–5 y at baseline, the effect of the intervention on reducing the prevalence of serum retinol <1.05 μmol/L approached significance ($P < 0.10$). There are several factors to consider in interpreting this modest impact among children.

The mean increase in vitamin A RAE intakes was >100% of the age-specific EAR, an amount within the range observed to improve vitamin A status among children in efficacy trials (14,16,34–36). Smaller scale, controlled, effectiveness studies have also demonstrated a high uptake of OSP (17) or pro-vitamin A-rich fruits and vegetables (37) following relatively intensive interventions. The study introducing OSP to rural households in Mozambique on which the present study was modeled (17) resulted in a significant increase in serum retinol. This was associated with a net mean increase in vitamin A RAE intake equivalent to 176% of the age-specific EAR, which is greater than the relative increase observed in the present study. The children in Mozambique also had very low nonintervention vitamin A intakes (postintervention control group, 56 μg RAE/d) and a much higher baseline prevalence of VAD compared with the children in Uganda (70–73% vs. 29–30%), which would have increased the likelihood of observing a significant change in vitamin A status in Mozambique.

We observed a very high prevalence of infection (~79%) among children at baseline and follow-up. It was thus not feasible to consider only noninfected individuals in the impact analysis and we therefore controlled for these indicators of infection in the regression models. Nonetheless, the confounding effect of infection occurred at both baseline and follow-up and hence the ability to detect changes in serum retinol concentration between time points may have been greatly reduced. Beyond the acute-phase response, the impact of repeated infections on vitamin A status is not possible to quantify but may be important (38).

Another challenge in measuring intervention impact in this population was that it may have taken place in the context of a secular trend for improving vitamin A status, particularly among women. Selection of this population was based on the prevalence of VAD (serum retinol <0.70 μmol/L from blood spots) of 27.9% for children 6–59 mo of age and 22.7% for women from a 2000–2001 national survey (8). The 2006 national survey indicated VAD (retinol binding protein from dried blood spots <0.82 μmol/L) prevalences of 20.4 and 3.4% for children and women, respectively (39). Although different biochemical methods were used, these data suggest a sharp decline in VAD among women and a moderate decline among children. In our 2007 baseline survey, we also observed a very low prevalence of VAD among women (2%) but higher rates among children (27–30%). By follow-up, this was only 16–20% among children aged 5–7 y regardless of the intervention.

The apparent secular decline in VAD coincided with the time that vitamin A fortification of vegetable oil and fats expanded, after introduction in 2004 (11), and with an increase in reported coverage of vitamin A supplementation. We estimated fortified vegetable oil and fat to provide only 4–9% of total vitamin A. The reported coverage rates for vitamin A supplementation among children 6–59 mo of age were low in the national surveys for 2000–2001 (38%) and 2006 (36%) (8,39) and reached 67% in 2008 (9). Although children >5 y of age are no longer eligible to receive high-dose vitamin A supplements during Child Health

TABLE 4 Change in vitamin A status among children and women in IP with baseline infection-adjusted serum retinol <1.05 μmol/L following an intervention introducing OSP in rural Uganda[1]

	Baseline serum retinol <1.05 μmol/L								
	Children 3–5 y at baseline (n = 472) with complete data for serum retinol, CRP, and AGP			Children 3–5 y at baseline (n = 396) with complete data for serum retinol, CRP, AGP, and other covariates			Women (n = 95)		
	Serum retinol, *μmol/L*	Serum retinol <1.05 μmol/L, %	Serum retinol <0.70 μmol/L, %	Serum retinol, *μmol/L*	Serum retinol <1.05 μmol/L, %	Serum retinol <0.70 μmol/L, %	Serum retinol, *μmol/L*	Serum retinol <1.05 μmol/L, %	Serum retinol <0.70 μmol/L, %
IP[2]	−0.005 ± 0.030	−0.076 ± 0.044	0.032 ± 0.033	0.002 ± 0.031	−0.095 ± 0.045*	0.036 ± 0.036	0.110 ± 0.102	−0.019 ± 0.084	−0.025 ± 0.044
Serum CRP >5.0 mg/L	−0.231 ± 0.078**	0.198 ± 0.121	0.273 ± 0.140	−0.222 ± 0.081**	0.184 ± 0.114	0.268 ± 0.142	−0.007 ± 0.190	−0.019 ± 0.234	−0.044 ± 0.035
Serum AGP >1.0 g/L	0.003 ± 0.038	−0.046 ± 0.069	0.020 ± 0.038	0.009 ± 0.043	−0.042 ± 0.075	−0.001 ± 0.042	0.150 ± 0.162	−0.138 ± 0.116	−0.068 ± 0.031
Serum CRP × AGP[3]	0.053 ± 0.087	0.011 ± 0.137	−0.072 ± 0.154	0.058 ± 0.089	−0.006 ± 0.130	−0.055 ± 0.157	−0.386 ± 0.241	0.431 ± 0.266	0.114 ± 0.060
Age, mo	—	—	—	0.004 ± 0.002*	−0.006 ± 0.002**	−0.003 ± 0.003	—	—	—
Dewormed in past 12 mo	—	—	—	0.040 ± 0.030	−0.122 ± 0.056*	0.003 ± 0.041	—	—	—
Vitamin A supplement in past 12 mo	—	—	—	0.036 ± 0.045	0.007 ± 0.094	−0.065 ± 0.060	—	—	—
R^2	0.130	0.095	0.096	0.165	0.148	0.122	0.087	0.074	0.063

[1] Sample was restricted to individuals with adjusted baseline serum retinol <1.05 μmol/L, where adjustment to retinol for stage of infection is based on correction factors estimated from this sample (26). Unadjusted serum retinol at follow-up was used in the model. Data are conditional means ± SE adjusted for the cluster (farmer group) and stratification (district) design of the survey. The regression model also controls for district and sex (coefficients not shown). The impact of the intervention is given by the coefficient on IP representing a single difference, where the difference in μmol/L or prevalence of retinol <1.05 or <0.70 μmol/L between control and IP groups are conditional on covariants. Test statistics are t statistics: *P < 0.05, **P < 0.01. IP, intensive program; OSP, orange sweet potato.

[2] IP represents the intervention, where farmer group-level intervention components continued for 2 y. The reference is the control group, where farmer group-level intervention components were absent.

[3] Interaction term for serum CRP, >5.0 mg/L × serum AGP, >1.0 g/L.

TABLE 5 Association of dietary vitamin A intake by source with unadjusted serum retinol and VAD among children and women in IP with infection-adjusted serum retinol <1.05 μmol/L at baseline, following an intervention to introduce OSP in rural Uganda[1]

	Baseline adjusted serum retinol <1.05 μmol/L				
	Children 3–5 y at baseline (n = 199)			Women (n = 33)	
	Serum retinol, μmol/L	Serum retinol <1.05 μmol/L	Serum retinol <0.70 μmol/L	Serum retinol, μmol/L	Serum retinol <1.05 μmol/L
Vitamin A,[2] *mg RAE/d*					
OSP	0.046 ± 0.017**	−0.103 ± 0.039*	−0.048 ± 0.022*	0.270 ± 0.197	−0.145 ± 0.050**
Yellow sweet potato	0.027 ± 0.035	−0.032 ± 0.062	−0.051 ± 0.050	0.019 ± 0.184	0.149 ± 0.164
Non-sweet potato sources	0.056 ± 0.052	−0.296 ± 0.098**	−0.018 ± 0.060	−0.039 ± 0.286	−0.004 ± 0.249
Serum CRP >5.0 mg/L	−0.140 ± 0.047**	0.187 ± 0.073*	0.141 ± 0.073	−0.412 ± 0.098**	0.730 ± 0.142**
Serum AGP >1.0 g/L	0.034 ± 0.051	0.005 ± 0.095	−0.080 ± 0.055	0.364 ± 0.280	0.039 ± 0.210
Serum CRP × AGP[3]	−0.001 ± 0.001	0.001 ± 0.001	0.003 ± 0.001**	−0.369 ± 0.306	−0.274 ± 0.307
R^2	0.174	0.194	0.139	0.339	0.246

[1] Sample was restricted to individuals with adjusted baseline serum retinol <1.05 μmol/L, where adjustment to retinol for stage of infection was based on correction factors estimated from this sample (26). Unadjusted serum retinol at follow-up was used in the model. Data are conditional means ± SE adjusted for the cluster (farmer group) and stratification (district) design of the survey. The model controls for district and sex (coefficients not shown). None of the women had serum retinol <0.70 μmol/L, so this model was omitted. Test statistics are t statistics: *$P < 0.05$, **$P < 0.01$. IP, intensive program; OSP, orange sweet potato; RAE, retinol activity equivalents; VAD, vitamin A deficiency.
[2] Vitamin A intake data were rescaled to mg RAE/d from μg RAE/d, as presented elsewhere in the manuscript.
[3] Interaction term for serum CRP, >5.0 mg/L × serum AGP, >1.0 g/L.

Week in Uganda, ~70% of the children 5–7 y old at follow-up in our study reportedly received a vitamin A supplement during Child Health Week ~4 mo before the follow-up survey. Continued dosing with vitamin A may have reduced the sensitivity to detect the impact of the intervention.

Despite these many challenges, we did find that at follow-up, vitamin A intake from OSP was a significant, positive predictor of vitamin A status and that the prevalence of serum retinol <1.05 μmol/L was reduced by 9.5 percentage points ($P < 0.05$) among the subset of children with complete data for important confounding factors. Collectively, these results provide support for the contribution of OSP to improving vitamin A status, while highlighting the challenges in establishing biological impact from programs in the context of a changing nutritional landscape.

Sweet potato is a seasonal crop and therefore this intervention would not provide the same amount of additional vitamin A throughout the entire year. However, in these communities, sweet potato is harvested 2–3 times/y and OSP would be available for ~9–10 mo/y. The increase in vitamin A intake cannot necessarily be extrapolated to non-farmer group member households. Individuals engaged in social and learning groups may be more highly motivated with a greater capacity for farm production. Additional surveys are underway to measure the diffusion of OSP to non-farmer group member households.

In conclusion, a large-scale intervention to introduce OSP to farmer group member households in Uganda resulted in the incorporation of OSP into the diets of women and children and a large increase in vitamin A intake. We observed evidence for a significant contribution of the intervention to improved vitamin A status among children at greatest risk of VAD. β-Carotene–rich OSP introduced in a population where sweet potato is an important staple food can be an important part of food-based strategies to minimize the risk of dietary VAD.

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Literature Cited

1. WHO. Global prevalence of vitamin A deficiency in populations at risk 1995–2005. WHO Global Database on Vitamin A Deficiency. Geneva: WHO; 2009.
2. Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, Ezzati M, Mathers C, Rivera J, Maternal and Child Undernutrition Study Group. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet. 2008;371:243–60.
3. Beaton GH, Martorell R, Aronson KJ, Edmonston B, McCabe G, Ross AC, Harvey B. Effectiveness of vitamin A supplementation in the control of young child morbidity and mortality in developing countries. United Nations Administrative Committee on Coordination, Sub-committee on Nutrition State-of-the-Art Series: nutrition policy discussion paper no. 13. Geneva: United Nations; 1993.
4. WHO. Vitamin A deficiency and xerophthalmia. Report of a joint WHO/USAID meeting. WHO Technical Report Series 590. Geneva: WHO; 1976.
5. West KP Jr, Gernand A, Sommer A. Vitamin A in nutritional anemia. In: Kraemer K, Zimmermann MB, editors. Nutritional anemia. Basel: Sight and Life Press; 2007. p. 133–53.
6. Christian P, West KP Jr, Khatry SK, Katz J, LeClerq S, Kimbrough Pradhan E, Shrestha SR. Vitamin A or β-carotene supplementation reduces but does not eliminate maternal night blindness in Nepal. J Nutr. 1998;128:1458–63.
7. Bouis HE, Hotz C, McClafferty B, Meenakshi JV, Pfeiffer W. Biofortification: a new tool to reduce micronutrient malnutrition. Food Nutr Bull. 2011;32:S31–40.

8. Uganda Bureau of Statistics and ORC Macro. Uganda Demographic and Health Survey, 2000–2001. Calverton (MD): UBOS and ORC Macro; 2001.
9. UNICEF. State of the world's children. Special edition. Statistical tables. New York: UNICEF; 2009.
10. Allen LH, Haskell M. Estimating the potential for vitamin A toxicity in women and young children. J Nutr. 2002;132:S2907–19.
11. Harvey P, Rambeloson Z, Dary O. The 2008 Uganda food consumption survey. Determining the dietary patterns of Ugandan women and children. Washington, DC: Academy for Educational Development; 2010.
12. FAO. FAOSTAT food balance sheets. Rome; 2007 [cited 2010 Oct 11]. Available from: http://faostat.fao.org/site/368/DesktopDefault.aspx?PageID=368#ancor.
13. Takahata Y, Noda T, Nagata T. HPLC determination of β-carotene content of sweet potato cultivars and its relationship with color values. Japan J Breed. 1993;43:421–7.
14. Jalal F, Nesheim MC, Agus Z, Sanjur D, Habicht JP. Serum retinol concentrations in children are affected by food sources of β-carotene, fat intake, and anthelmintic drug treatment. Am J Clin Nutr. 1998; 68:623–9.
15. Haskell MJ, Jamil KM, Hassan F, Peerson JM, Hossain MI, Fuchs GJ, Brown KH. Daily consumption of Indian spinach (*Basella alba*) or sweet potatoes has a positive effect on total-body vitamin A stores in Bangladeshi men. Am J Clin Nutr. 2004;80:705–14.
16. van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Spinnler Benade AJ. β-Carotene-rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. Am J Clin Nutr. 2005; 81:1080–7.
17. Low JW, Arimond M, Osman N, Dunguara B, Zano F, Tschirley D. Orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. J Nutr. 2007;137:1320–7.
18. Gibson RS, Ferguson EL. An interactive 24-hour recall for assessing the adequacy of iron and zinc intakes in developing countries. HarvestPlus technical monograph 8. Washington, DC: HarvestPlus; 2008.
19. Hotz C, Abdelrahman L, Sison C, Moursi M, Loechl C. A food composition table for central and eastern Uganda. Washington, DC: HarvestPlus; 2011.
20. USDA, Agricultural Research Service, USDA Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference, release 21. Beltsville (MD): USDA; 2008.
21. Food and Nutrition Board, Institute of Medicine. Dietary reference intakes: applications in dietary assessment. Washington, DC: National Academy Press; 2000.
22. Nusser SM, Carriquiry AL, Dodd KW, Fuller WA. A semi-parametric approach to estimating usual nutrient intake distributions. J Am Stat Assoc. 1996;91:1440–9.
23. Fuller WA. Measurement error models. New York: Wiley, 1987.
24. Food and Nutrition Board and Institute of Medicine. Vitamin A. In: Dietary Reference Intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: National Academy Press; 2001.
25. Bengtsson A, Namuebi A, Larsson Alminger M, Svanberg U. Effects of various traditional processing methods on the all-trans-β-carotene content of orange-fleshed sweet potato. J Food Compost Anal. 2008;21:134–43.
26. Thurnham DI, McCabe GP, Northrop-Clewes CA, Nestel P. Effects of subclinical infection on plasma retinol concentrations and assessment of prevalence of vitamin A deficiency: meta-analysis. Lancet. 2003;362: 2052–8.
27. Craft NE, Furr HC, Price L. Vitamin A in dried blood spots: update on HPLC method changes to measure retinol. Abstract T57. Washington, DC: Micronutrient Forum; 2007.
28. WHO Multicentre Growth Reference Study Group. WHO child growth standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development. Geneva: WHO; 2006.
29. Pilch SM. Analysis of vitamin A data from health and nutrition examination surveys. J Nutr. 1987;117:636–40.
30. Box GEP, Cox DR. An analysis of transformations. J R Stat Soc Series B Stat Methodol. 1964;26:211–52.
31. Tomlins K, Ndunguru B, Stambul K, Joshua N, Ngendello T, Rwiza E, Amour R, Ramadhani B, Kapande A, Westby A. Sensory evaluation and consumer acceptability of pale-fleshed and orange-fleshed sweetpotato by school children and mothers with preschool children. J Sci Food Agric. 2007;87:2436–46.
32. Chowdhury S, Meenakshi JV, Tomlins KI, Owori C. Are consumers in developing countries willing to pay for micronutrient-dense biofortified foods? Evidence from a field experiment in Uganda. Am J Agric Econ. 2011;93:83–97.
33. WHO. Complementary feeding of young children in developing countries: a review of current scientific knowledge. Brown KH, Dewey K, Allen L, editors. Geneva: WHO; 1998.
34. de Pee S, West CE, Permaesih D, Martuti S, Muhilal, Hautvast JGAJ. Orange fruit is more effective than are dark-green, leafy vegetables in increasing serum concentrations of retinol and β-carotene in school-children in Indonesia. Am J Clin Nutr. 1998;68:1058–67.
35. Tang G, Gu X-F, Hu S-M, Su Q-M, Qin J, Dolnikowski GG, Fjeld CR, Gao X, Russell RM, Yin S-A. Green and yellow vegetables can maintain body stores of vitamin A in Chinese children. Am J Clin Nutr. 1999;70:1069–76.
36. Vuong T, Dueker SR, Murphy SP. Plasma β-carotene and retinol concentrations of children increase after a 30-d supplementation with the fruit Momordica cochinchinensis (gac). Am J Clin Nutr. 2002; 75:872–9.
37. Faber M, Phungula MAS, Venter SL, Dhansay MA, Spinnler Benade AJ. Home gardens focusing on the production of yellow and dark-green leafy vegetables increase the serum retinol concentrations of 2–5 y-old children in South Africa. Am J Clin Nutr. 2002;76:1048–54.
38. Miller M, Humphrey J, Johnson E, Marinda E, Brookmeyer R, Katz J. Why do children become vitamin A deficient? J Nutr. 2002;132:S2867–80.
39. Uganda Bureau of Statistics and Macro International Inc. Uganda demographic and health survey 2006. Calverton (MD): UBOS and Macro International Inc; 2007.