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A Food-Based Approach Introducing Orange-Fleshed Sweet Potatoes Increased Vitamin A Intake and Serum Retinol Concentrations in Young Children in Rural Mozambique[1–3]

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Abstract

Vitamin A deficiency is widespread and has severe consequences for young children in the developing world. Food-based approaches may be an appropriate and sustainable complement to supplementation programs. Orange-fleshed sweet potato (OFSP) is rich in β-carotene and is well accepted by young children. In an extremely resource poor area in Mozambique, the effectiveness of introduction of OFSP was assessed in an integrated agriculture and nutrition intervention, which aimed to increase vitamin A intake and serum retinol concentrations in young children. The 2-y quasi-experimental intervention study followed households and children ($n = 741$; mean age 13 mo at baseline) through 2 agricultural cycles. In y 2, 90% of intervention households produced OFSP, and mean OFSP plot size in intervention areas increased from 33 to 359 m^2. Intervention children ($n = 498$) were more likely than control children ($n = 243$) to eat OFSP 3 or more d in the last wk (55% vs. 8%, $P < 0.001$) and their vitamin A intakes were much higher than those of control children (median 426 vs. 56 μg retinol activity equivalent, $P < 0.001$). Controlling for infection/inflammation and other confounders, mean serum retinol increased by 0.100 μmol/L (SEM 0.024; $P < 0.001$) in intervention children and did not increase significantly in control subjects. Integrated promotion of OFSP can complement other approaches and contribute to increases in vitamin A intake and serum retinol concentrations in young children in rural Mozambique and similar areas in Sub-Saharan Africa.   J. Nutr. 137: 1320–1327, 2007.

Introduction

Vitamin A deficiency (VAD)[11] is widespread in young children in the developing world; globally, 127 million children are estimated to be affected (1). VAD can limit growth, weaken immunity, cause xerophthalmia leading to blindness, and increase mortality (2). The problem is severe in Mozambique, with an estimated prevalence of 71% in children 6–59 mo (3). The 3 most common strategies for combating VAD are distribution of vitamin A supplements, food fortification, and food-based approaches that aim to increase access to and intake of vitamin A-rich foods. Although supplementation and fortification programs can be effective, sustainability has been an issue in some contexts, and an integrated strategy may be optimal (4).

Food-based approaches have been reviewed and judged to have a promising role in integrated strategies (5), but many gaps in knowledge were identified; more well-designed studies on efficacy, effectiveness, cost effectiveness, and sustainability of food-based approaches are needed. Recently, several small, controlled feeding trials showed increased serum retinol or improvements in vitamin A status after relatively short periods (3 wk–4 mo) of feeding β-carotene-rich plant foods, in some cases in combination with a fat source and/or deworming (6–11). In 3 of these trials, β-carotene was provided by orange-fleshed sweet potato (OFSP) (6,10,11).

OFSP is a particularly promising food, because levels of β-carotene are extremely high in many varieties [100–1600 μg retinol activity equivalent (RAE)/100 g for varieties in Africa] and it is generally well accepted by young children (12,13). OFSP is also a good source of energy (293 to 460 kJ/100 g),[12] easy to cultivate, vegetatively propagated, and fairly drought resistant once established; these characteristics make OFSP an excellent food security crop. Sweet potato is less labor intensive than most other staple crops and can be planted over a broad range of time without considerable yield loss (14).

Community trials to assess the effectiveness of food-based interventions are challenging to design and few well-designed studies have been reported, especially in Sub-Saharan Africa (SSA) (5,15). Appropriate control groups can be difficult to identify and the interventions themselves may be complex, involving agricultural extension, nutrition education, and behavior change communication strategies. Few interventions include market development, but this may be essential for assuring sustained adoption of a food-based approach. This study was designed to meet these challenges and to assess the effectiveness of introducing OFSP in an integrated agriculture and nutrition intervention aimed at increasing vitamin A intake and serum retinol concentrations in young children.

Subjects and Methods

Research setting and project partners. The 2-y intervention research project was undertaken in drought-prone areas of Zambézia Province (Central Mozambique), which are characterized by high levels of young child malnutrition, a monotonous diet with cassava as the primary staple, and a very poor resource base. White-fleshed varieties of sweet potato were already widely cultivated and consumed in the area. Project partners included Michigan State University, the Nutrition Division of Ministry of Health, Mozambique (MISAU), World Vision Mozambique, the National Institute for Agronomic Investigation, the Southern African Root Crops Research Network, and Helen Keller International.

Study design and recruitment. The study was quasi-experimental, prospective, controlled, and longitudinal, initially involving 827 households in 3 districts (Mopeia, Namacurra, and Nicoadala). The 3 districts were purposely selected because of the following features: the implementing partner (World Vision Mozambique) was operating in the intervention districts (Mopeia, Namacurra); high levels of malnutrition and vulnerability to drought (and thus potential to benefit) existed there; there was a common dominant language; and it would be feasible for extension staff to travel throughout the districts. Two districts were selected for intervention and 1 as a control.

Within intervention and control districts, villages were stratified by distance to basic services. Villages in intervention districts were randomly selected with probability of selection proportional to size. Villages in the control district were also selected with probability of selection proportional to size but were eliminated if OFSP had been distributed in the area or if there were plans for distribution. Complete household listings were conducted and all households with an age-eligible child (4–38 mo) were invited to participate. In the intervention villages, participation in the study entailed membership in a farmers' group; control villages had no such requirement. Thirty-eight percent of eligible households agreed to participate in the intervention villages compared with 64% in control villages. We addressed the potential threat to internal validity posed by selection bias analytically through use of a child-level fixed effects model and through control for household-level confounders (see below).

There were no exclusion criteria at the outset of the study. Severely wasted children (weight-for-height Z score < -3; $n = 2$) and those with very low hemoglobin (<70 g/L; $n = 170$) were referred to health facilities

[12] 70 to 110 kcal/100 g (1 kcal = 4.184 kJ).

for treatment but remained part of the study. The purposes of the study were explained in village meetings. A declaration of consent was read to each study household in the dominant language (Chuabo) and was signed by both the principal woman and man in the household before data collection. The study protocol was reviewed and approved by the ethics review committees of the Micronutrient Initiative of Canada and Michigan State University (United States) and the National Bioethics Committee for Health of Mozambique.

Sample size. The principal outcome used in this study was mean serum retinol concentration. In efficacy trials under controlled conditions, intergroup differences have been demonstrated with small samples. With 44–49 subjects per group, de Pee et al. (16) detected significant differences in mean serum retinol concentration (0.07–0.12 μmol/L) between groups. Effectiveness studies encounter greater variation as frequency and quantity of consumption are not controlled and other conditions may lower absorption or increase losses of vitamin A. This study was designed to detect a between-group difference of 0.05 μmol/L, with a power of 0.95 and a significance level of 0.05. This required 250 children in each of the 2 intervention districts and in a control district. We therefore aimed to recruit 825 households to allow for 10% loss to follow-up.

Study interventions. The intervention was based on a program model with 3 necessary and linked elements. To succeed in substantially increasing production of OFSP and vitamin A intake, the project aimed to simultaneously: *1*) increase farmers' access to OFSP vines; *2*) increase nutrition knowledge and create demand for OFSP; and *3*) ensure sustainability through market development. A wide variety of activities were undertaken, including community theater and radio spots and a visible presence at local markets.

Integrated farmer extension was a core intervention activity. Eight extension agents lived in centrally-located villages in the study areas and worked in pairs (a male agricultural agent and a female nutrition agent) with the same 53 farmers' groups; in 2003 718 women farmers and 323 men participated in the groups. Agricultural topics covered included production methods, storage, and commercialization of OFSP. Nutrition extension activities were based on formative research and trials of improved practices (17). Group education sessions included lectures using visual aids and a variety of interactive methods such as recipe demonstrations and role playing that conveyed messages regarding infant and young child feeding and hygiene practices. Participants had the opportunity to attend from 9 to 12 sessions (depending on site) over a 1-y period.

Study protocol. Nine surveys were undertaken. Information was gathered on socioeconomic and demographic characteristics of households, agricultural production, child morbidity, adult and child anthropometry, parental nutrition knowledge, food frequency, dietary intakes, and biochemical indicators. The aims were to: *1*) establish baseline comparability; *2*) characterize intermediate changes in the pathway toward impact (e.g. knowledge, OFSP production and consumption, vitamin A intakes); and *3*) measure impact on serum retinol concentrations. Most topics were covered in multiple surveys to capture change across the life of the project (**Supplemental Fig. 1**). Dietary intake was assessed using 24-h recalls during the sweet potato harvest season each year. A simple FFQ determined how many days in the last week the child had eaten OFSP and other vitamin A-rich foods and fat sources; the FFQ was repeated 7 times to capture seasonal variation and change across the 2 y. The incidence and severity of child morbidity during the 2 wk prior to nutritional status assessment was based on the recall of the principal caregiver. Blood samples were collected from all study children for biochemical analysis (see below). In addition to the survey data collection, sweet potato plots were measured annually and prices of major sources of vitamin A were monitored monthly in 5 markets.

Vitamin A supplementation protocol. At the time of the study, MISAU protocols included vitamin A capsule distribution twice yearly as part of routine clinic contacts. The national coverage rate in 2003 for rural areas was estimated at 43% (18). Given the known high prevalence of VAD in Mozambique, the research protocol included distribution of vitamin A capsules to ensure study children were not placed at undue

risk. All study children in both intervention and control areas received 3 capsules (60,000 μg retinyl palmitate per capsule) during the course of the study, with capsule distribution immediately following blood sample collection (see below) at 3 time points.

Capsules were distributed at baseline (May–June 2003), 6 mo later (November 2003–January 2004), and at the end of the study (November 2004–January 2005). Intervention children did not routinely receive capsules from either the project or local clinics between distribution 2 and the final distribution (a period of ~12 mo).[13] Thus, the study tested whether the intervention could increase intervention child intakes sufficiently to maintain or increase serum retinol, relative to control children, in the absence of supplementation during this 12-mo period. During the same 12-mo period, control area clinics followed the MISAU protocol to supplement during routine clinic contacts, but only 24 children (9.9%) received capsules.

Blood sample collection and biochemical analyses. Serum retinol concentration is transiently depressed in the presence of inflammation (19,20). Acute phase proteins, such as plasma C-reactive protein (CRP), are markers for inflammation/infection and have been used to help distinguish low serum retinol due to infection and inflammation from that due to inadequate intakes and body stores (9,21,22). CRP levels of >5.0 mg/L indicate acute infection/inflammation (23); note that CRP may be elevated in the absence of any reported clinical symptoms.

Serum retinol and CRP were measured 3 times in all study households: at baseline, 6 mo after baseline, and 12 mo later at the end of the study. Serum retinol and CRP were determined using dried blood spots (DBS) (nonfasting capillary blood samples from finger sticks). Three nurses and 1 nutritionist were seconded by MISAU for the duration of the project and were trained for 2 wk in DBS collection by staff from the National Institute of Health of Mozambique. Distribution of vitamin A capsules followed blood sample collection and the time elapsed between receipt of the previous capsule and the subsequent blood sample was the same for intervention and control children.

All materials for DBS sample collection were purchased from Craft Technologies. The team collected all blood spots on filter papers inside community facilities under darkened conditions. The filter papers were immediately placed for 24–48 h in drying boxes equipped with filter paper separators. After returning to headquarters, each sample was placed between wax-like separating papers and then in a zip-locked bag with desiccant packets. Bags of 10–20 samples were stored in a freezer until at least 100–150 samples had been collected; desiccant was renewed every 48 h. All samples were shipped to Craft Technologies and kept frozen until analysis. Serum retinol and CRP concentrations were determined by Craft Technologies technicians who were unaware of whether the sample was from an intervention or a control area.

Serum retinol concentrations were determined using HPLC (24). The method was as previously validated and described (25), with the following modifications: DBS were eluted in water without ascorbic acid or Triton X-100. A total of 100 mL eluate was removed prior to adding acetonitrile and sodium was measured in the eluate with a Horriba C-122 Cardy Sodium Meter (Cole-Palmer). The limit of retinol quantitation was 0.05 μg/mL serum (0.17 μmol/L). The reproducibility of retinol in control samples was ±10%. CRP was determined by ELISA as previously described (26), with adjustment to account for the serum volume recovered from a 3-mm hole punch of dried whole blood. The lower limit of detection for this assay was 0.2 mg/L.

Nutrition knowledge assessment. Nutritional knowledge was assessed in principal caregivers at baseline and endline using a structured survey instrument. To quantify the change in nutritional knowledge over time, a simple score was created assigning 1 point for each correct answer to 4 questions concerning vitamin A (awareness of vitamin A and knowledge of its 3 principal functions), 5 questions on breastfeeding (value of giving colostrum, exclusive breastfeeding, and maintaining breastfeeding when caregiver is ill, pregnant, or milk has stayed long in the breast), and 3 questions on young child feeding practices (appropriate age of introduction of complementary foods, appropriate frequency of feeding at 9 mo and 2 y of age). All questions included in the score were covered in nutrition education sessions in intervention areas and/or through mass media messages. Control households could have been exposed to some messages through radio programs.

Dietary data collection. Dietary data were collected in homes and all days of the week were equally represented. We obtained 24-h recall data using volumetric estimates of quantities consumed. Enumerators were carefully trained and carried containers marked in milliliters. For ingredients such as rice and flour, the person who had prepared the food was asked to demonstrate how much she used of each ingredient, using her own container or other method (e.g. handfuls). Then the enumerator transferred that amount into a container to estimate volume. In the case of vegetables such as tomatoes, enumerators carried small-, medium-, and large-sized models and asked the respondent to specify the size and quantity of each used. In addition to estimating the amount of each ingredient, the enumerators estimated the total volume of any prepared dish and the volume leftover. Finally, the respondent was asked to demonstrate the amount of each dish or ingredient consumed by the child. Tables were prepared to convert milliliters and standard models into grams.

For commonly eaten mixed dishes ($n = 17$), volumes of foods as eaten (raw or cooked) were determined using raw-to-cooked conversion factors obtained through in-home observations. The majority of nutrient values for foods as eaten came from version 16 of the USDA food composition table (FCT) (27) and an East African FCT (28). For OFSP (cooked), a value of 788 μg/100 g was used (29,30), reflecting values found in varieties used in SSA, which on average are lower than USDA values. Total vitamin A intakes were reported as RAE to reflect current knowledge regarding bioefficacy of carotenoids (31) and because the primary FCT (27) reported RAE. Retinol equivalent values taken from older tables (e.g. 28) were adjusted by dividing retinol equivalent values by 2 for plant sources.

Anthropometry. Child weight and length (if under 24 mo) or height were taken by a trained measurer and his/her assistant. The same enumerators were used in all survey rounds and were retrained prior to each round. Shorr height-length measuring boards were used (Shorr Productions). Each child was measured twice to the nearest 0.1 cm and measurements were repeated if they differed by >0.5 cm. Weight was measured to the nearest 0.1 g using digital Seca Model 881 Scales for Research. Z scores for height/length-for-age, weight-for-age, and weight-for-height were calculated using WHO Anthro 2005 (32). Children under 2 y were weighed nude; some older children wore light clothing and weights were adjusted for this.

Statistical analysis. All survey data were double-entered in CSPRO, versions 2.3–2.5, cleaned in SPSS versions 11.0 or 13.0, and analyzed in SPSS 13.0 or STATA 9.0. Incomes were estimated based on an income proxy model developed for use in Mozambique (33). Data were examined for normal distribution using the Shapiro-Wilk test of normality. For normally distributed data, independent sample t tests or Scheffé test were used to compare means between groups; paired t tests were used to compare the same groups in different survey rounds. Pearson chi-square or Fisher's exact test were used to assess differences in proportions. For nonnormally distributed data, nonparametric tests (Mann-Whitney U test or Wilcoxon's Signed Rank test) were used. All tests were 2-sided and probability levels of $P < 0.05$ were regarded as significant.

To determine the effect of the intervention on serum retinol, a child-level fixed effects regression model designed for longitudinal data (the *xtreg* procedure in Stata 9.0) was employed; this accounts for any preexisting observable or unobservable differences between the intervention and control children. Variables included in the model must change over time, so certain characteristics, such mothers' level of education,

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[13] Researchers coordinated carefully with local MISAU personnel to ensure that only the project provided capsules to study households at baseline, 6 mo after baseline, and the end of the study. In practice, only 3 intervention children received capsules from MISAU personnel contrary to protocol. Per project protocol, an additional 5 intervention children were given capsules when project blood sample collection revealed very low serum retinol mid-way between capsule distribution 2 and the final distribution.

cannot be included. Correlation matrices were examined and noncollinear household-level characteristics that differed between groups at baseline were included in the model. To adjust for the transient influence of infection/inflammation on serum retinol concentrations, a dummy variable for elevated CRP (>5 mg/L) was included to indicate the presence of inflammation/infection (23). Because extensive socioeconomic data were collected only at baseline and endline, the analysis was based on those 2 periods.

Results

Characteristics of households. Of the 827 households originally participating, 741 (90%) completed the study (498 and 243 in the intervention control areas, respectively).[14] Both areas are characterized by high levels of poverty; estimated median per capita income for 2002 was very low at ~$20 U.S. and did not differ between areas (**Table 1**). Households in intervention and control areas were also very similar at baseline in other dimensions, including ownership of assets and livestock, housing and sanitary conditions, and education levels of parents (some data not shown). Mothers' age, height, BMI, and parity were also very similar and nearly all the women described agriculture as their primary economic activity. Another key indicator illustrating the level of poverty in the study areas was the high proportion of women (46–53%) who had lost at least 1 child before the child reached 5 y of age.

Intervention and control households differed in the balance of income sources, with higher incomes from agricultural production in intervention areas balanced by higher nonagricultural income in the control area. Intervention and control households were equally likely to have grown sweet potato (70% of households), but median production was higher in intervention areas (73 kg vs. 60 kg in control area; $P < 0.001$). Agricultural production was identified as the main economic activity for most men in both areas, but the proportion was slightly higher in intervention areas. Conversely, more men in the control area reported having salaried employment and/or engaging in casual labor.

Child anthropometry and morbidity. At baseline, mean age (17.4 mo) and prevalence of low Z scores (<-2.0) (Table 1) did not differ between the intervention and control children. At the final measurement, prevalence of stunting (61%) did not differ, but prevalence of wasting and low weight-for-age were higher in the control area (6 vs. 3%, $P = 0.03$; and 34 vs. 24%, $P < 0.01$, respectively).

Reported prevalence of symptoms was high at baseline, with 81% of children ill in the previous 2 wk, and did not differ between intervention and control areas. In contrast, prevalence of high CRP (>5.0 mg/L) differed and was higher in control areas (74 vs. 59%, $P < 0.001$).

At final data collection, mean child age was 35 mo, and prevalence of morbidity had declined. Thirty-seven percent of the children were reported to have had some illness in the last 2 wk and, similarly, 36% of children had high CRP. Groups did not differ in any of the indicators of morbidity in this last round of data collection.

Nutrition session participation and nutritional knowledge of principal caregivers. Out of 9–12 available sessions, female

[14] Reasons for withdrawal included: household moved away (32), refused to continue (12), mother became severely ill (3), mother died and child was sent away (2), or child died. Thirty-seven children died, 26 (4.6%) in intervention and 11 (4.1%) in control areas.

TABLE 1 Baseline characteristics of households, parents, and children by study area

	Intervention study area, $n = 498$	Control study area, $n = 243$	P-value[1]
Assets and living conditions, %			
Owns radio	31	35	0.33
Owns bicycle	37	41	0.30
Has latrine	3	1	0.11
Access to improved well or piped water	19	24	0.08
Median Estimated income in 2002,[2] $US			
From agricultural production	9.7 (5.8–16.3)	7.1 (3.6–12.3)	<0.001
From all other sources	9.1 (5.3–15.1)	11.2 (6.8–17.6)	<0.001
Total per capita income	20.7 (13.8–31.7)	18.9 (13.2–31.0)	0.21
Mother's characteristics			
Age, y	27 (22–33)	26 (22–32)	0.74
BMI, kg/m^2	20.1 (19.0–21.4)	20.1 (19.0–21.1)	0.34
Have lost child <5 y, %	53	46	0.07
No formal education, %	61	61	0.97
Agriculture is principal activity, %	99	98	0.30
Principal man's[3] characteristics			
Age, y	32 (26–40)	33 (27–41)	0.28
Formal education, y	3 (0–5)	3 (0–5)	0.56
Agriculture is principal activity, %	90	83	0.01
Child nutritional status, %			
Height-for-age Z score <−2.0	60.3	65.1	0.22
Weight-for-age Z score <−2.0	37.7	44.4	0.09
Weight-for-height Z score <−2.0	10.8	14.0	0.22
Serum retinol concentration, $\mu mol/L$	0.59 (0.45–0.75)	0.55 (0.42–0.71)	0.12

[1] Values are median (interquartile range) or percent. P-value for comparison between intervention and control areas, Pearson's X^2 and Mann-Whitney U tests.
[2] Based on average Interbank exchange rate in 2002 of 23,051.25 Mozambican meticais to the U.S. dollar.
[3] A principal man is the father of the child or, when absent, the adult man in the family responsible for the welfare of the study child.

caregivers attended a mean of 7.8 sessions. When asked for the main reasons for missing sessions, most women (87%) reported this was due to their own illness and/or the need to care for another ill person.

At baseline, knowledge scores on the 12-point scale were very similar (mean scores 3.3–3.4) across all groups (men and women in intervention and control areas). At the end of the study, intervention women scored higher than at baseline (8.1) and higher than control women (4.3). Intervention men also improved their scores (6.3) and scored higher than control men (4.7) ($P < 0.001$ for all comparisons). Control men and women also improved their scores over baseline scores, but these 1.0–1.4 point increases were much smaller than those in intervention areas, where scores increased 4.8 points for women and 2.9 points for men.

Production and sale of OFSP and frequency of consumption by young children. Five of 9 introduced OFSP varieties were accepted by farmers both in terms of taste and agronomic performance. Households in farmers' groups expanded the area under production in y 2, increasing mean plot sizes from 33 to 359 m^2. Participation in sweet potato production and sales increased in intervention households during the study and declined slightly in control households, with 90% of intervention households growing OFSP in the final year (**Table 2**). Median total

TABLE 2 Household sweet potato production and sales activity at baseline (2002 production) and after intervention (2004 production) by study area

	Intervention study area, n = 498	Control study area, n = 243	P-value[1]
Produced any type of sweet potato, %			
2002	71	67	0.24
2004	94	56	<0.001
Produced OFSP, %			
2002[2]	5	0	<0.001
2004	90	11	<0.001
Produced and sold any type of sweet potato, %			
2002	13	18	0.02
2004	30	13	<0.001
Median (interquartile range) sweet potato production, kg			
2002	73 (0–180)	60 (0–126)	<0.001
2004	127 (51–261)	64 (20–126)	<0.001

[1] P-value for comparison between intervention and control areas, Pearson's χ^2 and Mann-Whitney U test.
[2] A total of 27 intervention households (5%) received OFSP prior to the onset of the study from preparatory adaptive research trials being conducted in the area.

sweet potato production for intervention households increased from 73 kg at baseline to 127 kg during the final study year, of which 71% was OFSP. In control households, median production remained very similar to baseline. The percentage of intervention households selling sweet potatoes increased from 13 to 30%, and in 2004 OFSP was the cheapest source of vitamin A on the market, costing 1 cent for 700 RAE.

The repeated FFQ showed clear increases in consumption of OFSP in study children in both areas (**Table 3**) and changes

TABLE 3 Percent of study children consuming OFSP 3 or more days during previous week by study area and survey round

Relation of food frequency survey to project timeline and cropping cycle	Intervention study area, n = 498	Control study area, n = 243	P-value[1]
Baseline: Jan–March 2003 Main rains, planting, initial group plots	1	0	0.44[3]
May–July 2003 Late in second rains; early sweet potato harvest	1	0	0.10[3]
Nov 2003–January 2004 Early rains, secondary harvest	17	2	<0.001
March–April 2004[2] Second rains, planting	8	—	—
May–July 2004[2] Late in second rains; early sweet potato harvest	15	—	—
August–October 2004 Dry season, main sweet potato harvest	54	4	<0.001
Nov 2004–January 2005 Early rains, secondary harvest	55	8	<0.001

[1] Values are percent. P-value for comparison between intervention and control areas, Pearson's χ^2.
[2] No measure in control area.
[3] Fisher's exact test.

between the initial and last FFQ were significant within each group ($P < 0.01$). However, the size of the increase was much larger in the intervention area. In the last 2 FFQ survey rounds, >50% of the children in the intervention area ate OFSP on at least 3 out of the last 7 d, as compared with 4–8% in the control area ($P < 0.001$).

Child dietary intake. Children's dietary intakes also differed between intervention and control areas near the end of the study, during the main OFSP harvest period (August–October, 2004) (**Table 4**). At this time, 7% of intervention children and 4% of control children were still breast-fed; breast-fed children were excluded from this comparison. Median intake of vitamin A was much higher ($P < 0.001$) in intervention children (426 μg RAE) compared with control children (56 μg RAE). Intakes were also higher for a range of other micronutrients and for energy. For all nutrient intakes that differed significantly, intervention children had higher values. OFSP contributed 35% to the vitamin A intakes of all children in the intervention area and 90% in those who consumed it the previous day. We also compared nutrient density between the 2 areas and found similar results (results not shown). Finally, because of the large amounts of OFSP eaten (median of 314 g in consumers), we compared nutrient intakes for consumers and nonconsumers to explore whether OFSP could be displacing other nutrient-dense foods. This did not appear to be the case and nutrient intakes of OFSP consumers were similar to or higher than those of nonconsumers across all nutrients (results not shown).

Impact of intervention on serum retinol concentration. To examine the impact of the intervention on serum retinol concentration, 8 intervention children who received vitamin A capsules between project capsule distributions 2 and 3 (final)

TABLE 4 Postintervention median nutrient intakes for nonbreast-fed children[1] by study area, during main sweet potato harvest season (2004)

	Intervention study area, n = 465		Control study area, n = 234		P-value[2]
Energy, kJ/d	5920	(4434–7750)	5133	(3839–6699)	<0.001
Protein, g/d	34	(21–50)	30	(19–48)	0.04
(% energy)	9.6		9.9		0.39
Lipids, g/d	17	(8–29)	15	(5–28)	0.13
(% energy)	11.0		11.1		0.86
Vitamin A, μg RAE/d	426	(61–1902)	56	(24–129)	<0.001
Retinol, μg/d	1.05	(0–17)	0.21	(0–17)	0.36
β-carotene, μg/d	2028	(122–22,264)	62	(0–669)	<0.001
Thiamin, mg/d	0.82	(0.45–1.22)	0.67	(0.28–1.03)	<0.01
Riboflavin, mg/d	0.41	(0.25–0.61)	0.27	(0.17–0.41)	<0.001
Niacin, mg/d	10.62	(7.08–15.85)	9.30	(6.05–13.63)	<0.01
Vitamin B-6, mg/d	0.85	(0.55–1.24)	0.67	(0.39–0.92)	<0.001
Folate, μg DFE/d	394	(139–643)	325	(60–524)	<0.01
Vitamin B-12, μg/d	0.49	(0.06–3.86)	0.72	(0.09–4.10)	0.30
Vitamin C, mg/d	114	(51–427)	43	(24–111)	<0.001
Calcium, mg/d	369	(214–712)	351	(170–736)	0.12
Iron, mg/d	9.77	(6.13–13.59)	8.48	(5.80–12.33)	0.02
Zinc, mg/d	4.68	(3.20–6.81)	4.15	(2.94–6.35)	0.05

[1] Values are median (interquartile range). Data from 24-h recall. Only 6% of children were breast-fed during this survey round. The difference in prevalence between areas approached significance ($P = 0.07$) so these children were excluded from nutrient intake comparisons.
[2] P-value for comparison between intervention and control areas, Mann-Whitney U test.

were excluded. However, 24 control children (10%) who received capsules from local health facilities were not excluded, because this represented the status quo coverage for nonintervention areas and our objective was to compare the intervention to the status quo. Excluding the 8 children did not significantly change any sample descriptive statistics (results not shown) and for simplicity, the remaining 733 children are hereafter referred to as "all children." To partially correct for the effect of inflammation/infection, we also examined a subsample of children with CRP values <5 mg/L, hereafter referred to as "healthy children."

At baseline, mean serum retinol between intervention and control children did not differ either in all children or in healthy children. At final blood sample collection, the unadjusted mean serum retinol concentration was higher ($P < 0.01$) for intervention children (0.74 μmol/L) compared with control children (0.67 μmol/L), with a difference of 0.07 μmol/L. The between-group difference was larger (0.09 μmol/L) when healthy intervention children (0.80 μmol/L) were compared with healthy control children at the end of the study (0.71 μmol/L; $P < 0.001$).

At baseline, prevalence of low serum retinol (< 0.70 μmol/L) did not differ either in all children or in the healthy children. By the end of the study, prevalence of low serum retinol was 10% lower ($P < 0.01$) in intervention children compared with control children (**Fig. 1**). In the healthy children in the intervention area, prevalence of low serum retinol dropped from 60% at baseline to 38%. In contrast, prevalence remained the same in healthy control children (52% at baseline vs. 53% at final blood sample collection) for a between-group difference of 15% ($P < 0.01$).

Longitudinal child-level fixed effects regression models were estimated with serum retinol as the dependent variable. The model controlled for the age of the child at time of measurement, presence of elevated CRP, and household characteristics that differed significantly between intervention and control groups at baseline (estimated nonagricultural income per capita and estimated agricultural income per capita). Other characteristics that differed significantly (number of plots, diversity of crops grown, participation in casual labor, etc.) were correlated with the relevant income component estimate and hence were not included. The coefficients for the intervention effect and for elevated CRP are highly significant and with the expected sign (**Supplemental Table 1**).

Adjusted mean serum retinol concentration did not differ between groups at baseline but was higher for intervention chil-
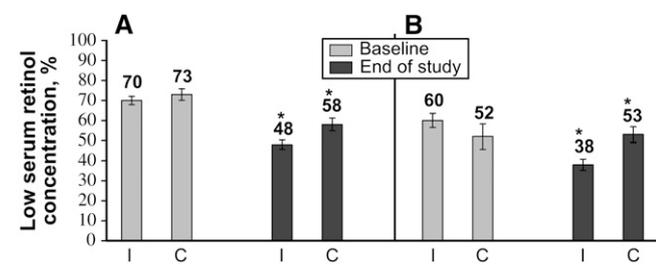
dren at endline (**Table 5**). The within-group difference between baseline and endline was significant for intervention children (0.100 μmol/L, $P < 0.001$) but not for control children. The difference in the change in serum retinol concentration is obtained by subtracting the baseline difference between intervention and control groups from the final (postintervention) difference between groups. The magnitude of this between-group "double difference" was 0.076 μmol/L ($P < 0.01$) (Table 5).

Discussion

This study was designed to assess whether an integrated package of agriculture, nutrition, and market interventions focused on introduction and promotion of OFSP could increase vitamin A intake and serum retinol concentrations in young children in Mozambique. To our knowledge, this study is the first food-based community-level intervention study in Africa that has followed the same intervention and control households and children throughout the initial adoption period, and the first food-based intervention to incorporate market development activities to help ensure sustained adoption of the agricultural component.

We documented a number of intermediate steps in the program model pathway and observed large differences between intervention and control areas for each. The new varieties were well accepted by farmers and by consumers, including targeted children. In intervention areas, mean sweet potato plot sizes were nearly 10 times higher in y 2 and OFSP emerged as the least expensive source of vitamin A in local markets. Nutrition knowledge increased in both men and women in the intervention area. For intervention children, the 24-h recall data suggested that OFSP was a major source of vitamin A, providing 90% of vitamin A for those children who consumed it the previous day

FIGURE 1 Percent of all children (*A*) and apparently healthy children (*B*) with low serum retinol concentration (<0.70μmol/L) at baseline and after 2-y intervention. A total of 8 children in intervention areas who had received vitamin A capsules in the 12 mo preceding the end of the study were excluded from both *A* and *B*. The apparently healthy child sample (*B*) excludes children with plasma CRP >5 mg/L in each round. Error bars represent 95% [CI]. For all children (*A*), $n = 490$ in intervention areas (I) and $n = 243$ in control areas (C). For healthy children (*B*), the sample size differs by round; at baseline, $n = 200$ for I and $n = 64$ for C. At the end of the study, $n = 310$ for I and $n = 163$ for C. *I is different from C, $P < 0.01$, chi-square test.

TABLE 5 Effect of the intervention on serum retinol (micromoles per liter), controlling for age, infection, and estimated income by source: between-group differences, within group changes, and double difference

			P-value
Adjusted mean difference between groups (intervention − control) within round			
Baseline,[1] $n = 733$	−0.002	(0.017)	0.91
End of study,[1] $n = 733$	0.074	(0.020)	<0.001
Adjusted mean within-group difference between rounds (end of study − baseline)			
Intervention,[1] $n = 490$	0.100	(0.024)	<0.001
Control,[1] $n = 243$	0.019	(0.032)	0.54
Adjusted mean difference between groups in change in serum retinol			
All children,[2] $n = 733$	0.076	(0.023)	<0.01

[1] Values are means ± SEM. Coefficients from regression model with standard errors correcting for heteroscedasticity shown in parentheses. Model adjusts for covariates: level of infection (CRP >5 mg/L), age in mo, and estimated household income per capita from nonagricultural and agricultural sources.
[2] Coefficients from xtreg procedure (StataCorp, version 9) fitting child-level fixed effects model to longitudinal data, with standard errors corrected for heteroscedasticity. Marginal effects evaluated at mean values for following variables included in xtreg model: binary dummy for CRP >5 mg/L (0.50), age in mo (26.1), estimated nonagricultural income per capita (11.4 U.S. dollars), and estimated agricultural income per capita (15.9 U.S. dollars).

and 35% for intervention children overall. Median vitamin A intakes were much higher for children in intervention areas compared with controls. FFQ results confirmed that OFSP was eaten regularly by intervention children during harvest season, with >50% having OFSP 3 or more days per week.

Finally, in the longitudinal model controlling for child age, CRP, and other potential confounders, serum retinol concentration increased by 0.100 μmol/L in intervention children and the "double difference" between intervention and control areas was 0.076 μmol/L. The first and final blood sample collections occurred during different seasons, but any unmeasured seasonal effects are accounted for by estimation of a double difference.

There are very few relevant comparisons for the impact of the intervention, because few studies have assessed the effectiveness of integrated agriculture-nutrition interventions in SSA and fewer have assessed impact on serum retinol (5,15). In rural Tanzania, a follow-up assessment was made 5 y after the conclusion of a 2-y intervention program that promoted gardens and fruit trees and included nutrition education (21). Although knowledge and practices were better in intervention than in control villages, mean serum retinol concentration was significantly lower, which the authors attribute to higher levels of helminth infection. In rural Kwa-Zulu Natal (South Africa), promotion of home gardening was integrated into an existing community-based growth monitoring program (34). Effectiveness was evaluated using pre- and postintervention cross-sectional surveys comparing 1 intervention village to a neighboring village. At follow-up, young children (2–5 y) in the intervention village reportedly ate vitamin A-rich fruits and vegetables more frequently and had higher mean serum retinol concentration (0.81 vs. 0.73 μmol/L in the control village). This study did not report any measurement or control for morbidity or baseline socioeconomic conditions; they did report baseline differences between the villages in access to protected water sources, toilets, and electricity and all these differences were in favor of the intervention village. They acknowledged the challenges in identifying appropriate control groups for studies of this type.

We also faced design challenges. We employed a pre-post longitudinal control group design, but due to funding and logistical constraints could only include those who chose to participate in farmers' groups in our intervention area study sample. In contrast, in the control area, we randomly sampled households. As a result, only 38% of households with age-eligible children are represented in our intervention area sample compared with 64% of households in the control area. This could have introduced bias if those who chose to participate were different from others in ways that related to our outcome. We addressed this potential for bias through measurement of a wide range of maternal and child-level factors, as well as indicators of household socioeconomic status (Table 1). Intervention and control households were similar across many dimensions and where they differed, differences were controlled for in longitudinal multivariate analysis. In addition, the child-level fixed effects model we employed controlled for baseline differences between the 2 groups of children. Overall, the socioeconomic characteristics of the study households at baseline were similar to those found for Zambézia province in a nationally representative household survey conducted the previous year (35).

The potential public health importance of intervention effect may be best illustrated by changes in prevalence (Fig. 1). In children with CRP <5 mg/L, prevalence of low serum retinol concentrations remained the same in control areas and dropped from 60 to 38% in intervention areas. In control areas, the final estimate of prevalence was nearly identical to baseline despite the fact that all children received 2 vitamin A capsules in y 1 of the study, along with access to capsules through MISAU channels during y 2. The low rate of coverage for control children during y 2 (10%) highlights the challenges to health service delivery in this very resource-poor environment. In this and similar contexts, food-based interventions may be most needed as complements to capsule distribution.

In intervention areas, the reduction in prevalence was substantial, but the final round prevalence of nearly 40% indicates considerable VAD (36) and highlights the need for multiple strategies. Nevertheless, our results demonstrate the potential for an integrated approach using OFSP as a key intervention to complement capsule distribution and other efforts and to contribute to increases in serum retinol in young children in rural Mozambique and similar areas. This should serve to underscore the relevance and importance of numerous efforts currently underway in the region. Driven in part by the devastating impact of the HIV/AIDS epidemic, less labor-intensive crops with flexible planting and harvest times, such as sweet potato, are being integrated into efforts to diversify diets and improve household food security. The Vitamin A for Africa partnership launched in May 2001 and currently including 10 member countries specifically seeks to promote OFSP to combat VAD in SSA (37). OFSP has also been selected as 1 of the leading crops for a major biofortification program, which aims to alleviate micronutrient deficiencies through enhancing the micronutrient content of staple foods (38).

A number of urgent program design and operational questions remain. To assess the potential of OFSP, our intervention involved an intensive package of activities. Although this allowed us to demonstrate the potential for success in a community setting, future research is urgently needed to identify the lowest cost set of activities required to achieve increases in young child vitamin A intake of a similar magnitude. Acceptability and ease of introduction of OFSP should also be explored in areas where there is the potential to produce OFSP but where there has been no previous cultivation of any type of sweet potato. The impact and public health importance of increased intakes will also vary depending on contextual conditions, including the underlying prevalence of deficiency and of helminthic and other infections and coverage of health services, among others. Therefore, further research in other contexts is warranted. Finally, research is also needed to confirm the longer-term sustainability of such interventions and to document challenges and successes in scaling-up to cover larger geographic areas.

Although further research will allow selection of the most cost-effective program packages, food-based approaches using OFSP clearly have potential to increase young child intakes and serum retinol concentrations in areas where baseline prevalence of deficiency is high and where any type of sweet potato has previously been cultivated. There is potential for very broad impact, because sweet potato is produced in parts of nearly all countries in the SSA region. Integration of agricultural and nutrition extension, along with market development, may maximize impact.

Literature Cited

1. West KP. Extent of vitamin A deficiency among preschool children and women of reproductive age. J Nutr. 2002;132:S2857–66.

2. Sommer A, West KP. Vitamin A deficiency: health, survival and vision. New York: Oxford University Press; 1996.

3. Aguayo VM, Kahn S, Ismael C, Meershoek S. Vitamin A deficiency and child mortality in Mozambique. Public Health Nutr. 2005;8:29–31.

4. Underwood B. Vitamin A deficiency disorders: international efforts to control a preventable "pox". J Nutr. 2004;134:S231–6.

5. Ruel MT. Can food-based strategies help reduce vitamin A and iron deficiencies? A review of recent evidence. Food Policy Review No. 5. Washington DC: International Food Policy Research Institute; 2001.

6. Jalal F, Nesheim MC, Agus Z, Sanjur D, Habicht JP. Serum retinol concentrations in children are affected by food sources of beta-carotene, fat intake, and anthelmintic drug treatment. Am J Clin Nutr. 1998;68: 623–9.

7. Tang G, Gu X, Hu S, Xu Q, Qin J, Dolnikowsk GG, Fjeld CR, Gao X, Russell RM, et al. Green and yellow vegetables can maintain stores of vitamin A in Chinese children. Am J Clin Nutr. 1999;70:1069–76.

8. Takyi EE. Children's consumption of dark green, leafy vegetables with added fat enhances serum retinol. J Nutr. 1999;129:1549–54.

9. Drammeh BS, Marquis GS, Funkhouser E, Bates C, Eto I, Stephensen CB. A randomized, 4-month mango and fat supplementation trial improved vitamin A status among young Gambian children. J Nutr. 2002; 132:3693–9.

10. van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Benade AJ. Beta-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.

11. 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.

12. Hagenimana V, Low J, Anyango M, Kurz K, Gichuki ST, Kabira J. Enhancing vitamin A intake in young children in Western Kenya: orange-fleshed sweetpotatoes and women farmers can serve as key entry points. Food Nutr Bull. 2001;22:370–87.

13. van Jaarsveld PJ, Marais DW, Harmse E, Nestel P, Rodriguez-Amaya DB. Retention of β-carotene in boiled, mashed orange-fleshed sweet potato. J Food Compos Anal. 2006;19:321–9.

14. Woolfe J. Sweet potato: an untapped resource. Cambridge: Cambridge University Press; 1992.

15. Berti PR, Krasevec J, FitzGerald S. A review of the effectiveness of agriculture interventions in improving nutrition outcomes. Public Health Nutr. 2004;7:599–609.

16. de Pee S, West CE, Permaesih D, Martuti S, Muhilal, Hautvast JG. Orange fruit is more effective than are dark-green, leafy vegetables in increasing serum concentrations of retinol and beta-carotene in school-children in Indonesia. Am J Clin Nutr. 1998;68:1058–67.

17. Dickin K, Griffiths M, Piwoz E. Designing by dialogue: a program planners' guide to consultative research for improving young child feeding. Washington DC: Academy for Educational Development; 1997.

18. Instituto Nacional de Estatística (INE). Ministério de Saúde; measure DHS+/ORC MACRO. Moçambique: inquérito demográfico e de saúde. Maputo, Mozambique: INE; 2005.

19. Stephensen CB, Gildengorin G. Serum retinol, the acute phase response, and the apparent misclassification of vitamin A status in the third National Health and Nutrition Examination Survey. Am J Clin Nutr. 2000;72:1170–8.

20. Wieringa FT, Dijkhuizen MA, West CE, Northrop-Clewes CA, Muhilal. Estimation of the effect of the acute phase response on indicators of micronutrient status in Indonesian infants. J Nutr. 2002;132:3061–6.

21. Kidala D, Greiner T, Gebre-Medhin M. Five-year follow-up of a food-based vitamin A intervention in Tanzania. Public Health Nutr. 2000; 3:425–31.

22. Siekmann JH, Allen LH, Bwibo NO, Demment MW, Murphy SP, Neumann CG. Kenyan school children have multiple micronutrient deficiencies, but increased plasma vitamin B-12 is the only detectable micronutrient response to meat or milk supplementation. J Nutr. 2003; 133:S3972–80.

23. Thurnham D, McCabe G, 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.

24. Craft NE, Bulux J, Valdez C, Li Y, Solomons NW. Retinol concentrations in capillary dried blood spots from healthy volunteers: method validation. Am J Clin Nutr. 2000;72:450–4.

25. Erhardt JG, Craft NE, Heinrich F, Biesalski HK. Rapid and simple measurement of retinol in human dried whole blood spots. J Nutr. 2002; 132:318–21.

26. Erhardt JG, Estes JE, Pfeiffer CM, Biesalski HK, Craft NE. Combined measurement of ferritin, soluble transferrin receptor, retinol binding protein, and C-reactive protein by an inexpensive, sensitive, and simple sandwich enzyme-linked immunosorbent assay technique. J Nutr. 2004; 134:3127–32.

27. USDA Agricultural Research Service. USDA National nutrient database for standard reference, release 16 [database on the Internet]. Washington: USDA. c2003 [cited 2006 Mar 26]. Available from: http:// www.nal.usda.gov/fnic/foodcomp.

28. West CE, Pepping F, Temalilwa CR. The composition of foods commonly eaten in East Africa. Wageningen (Netherlands):Wageningen Agricultural University; 1988.

29. van Jaarsveld PJ, Marais DW, Harmse E, Nestel P, Rodriguez-Amaya DB. Retention of β-carotene in boiled, mashed orange-fleshed sweet-potato. J Food Compos Anal. 2006;19:321–9.

30. Hagenimana V, Carey EE, Gichuki ST, Oyunga MA, Imungi JK. Carotenoid contents in fresh, dried and processed sweetpotato products. Ecol Food Nutr. 1999;37:455–73.

31. Institute of Medicine. 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; 2000.

32. WHO. WHO Anthro 2005, Beta version Feb. 17, 2006: software for assessing the growth and development of the world's children. Geneva: WHO; 2006 http://www.who.int/childgrowth/software/en1.

33. Tschirley D, Rose D, Marrule H. A methodology for estimating household income in rural Mozambique using easy-to-collect proxy variables. Maputo: Directorate of Economics, Ministry of Agriculture and Fisheries, Research Paper Series; 2000. Report No.: 38.

34. Faber M, Phungula MA, Venter SL, Dhansay MA, Benadé AS. Home gardens focusing on the production of yellow and dark-green leafy vegetables increase the serum retinol concentrations of 2–5 year old children in South Africa. Am J Clin Nutr. 2002;76:1048–54.

35. Boughton D, Mather D, Tschirley D, Walker T, Cunguara B, Payongayong E. Changes in rural household income patterns in Mozambique, 1996–2002, and implications for agriculture's contribution to poverty reduction. Maputo: Directorate of Economics, Ministry of Agriculture, Research Paper Series; 2006. Report No.: 61E.

36. Sommer A, Davidson FR. Assessment and control of vitamin A deficiency: The Annecy Accords. J Nutr. 2002;132:S2845–50.

37. Kapinga R, Anderson A, Crissman C, Zhang D, Lemaga B, Opio F. Vitamin A Partnership for Africa: a food based approach to combat vitamin A deficiency in Sub-Saharan Africa through increased utilization of orange-fleshed sweetpotato. Chron Horticult. 2005;45:12–4.

38. Bouis H. A new tool for fighting micronutrient malnutrition. Symposium: plant breeding: a new tool for fighting micronutrient malnutrition. J Nutr. 2002;132:S491–4.

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