Economic evaluation of nutrition-sensitive agricultural interventions to increase maternal and child dietary diversity and nutritional status in rural Odisha, India

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Abbreviations

NSA: nutrition-sensitive agriculture; PLA: Participatory Learning and Action; UPAVAN: Upscaling Participatory Action and Videos for Agriculture and Nutrition; SDG: Sustainable Development Goal; VARRAT: Voluntary Association for Rural Reconstruction and Appropriate Technology; JSI-RTI: John Snow Inc. Research and Training Institute; LSHTM: London School of Hygiene & Tropical Medicine; UCL: University College London; SHG: Self-help groups; AWWs: Anganwadi workers; ASHAs: Accredited Social Health Activists; ANMs: Auxiliary Nurse Midwives; CHEERS: Consolidated Health Economic Evaluation Reporting Standards; INR: Indian Rupees; GBP: British Pounds Sterling; NEEP-IE: The Nutrition Embedded Evaluation Programme Impact Evaluation; Mama SASHA: Sweetpotato Action for Security and Health in Africa; WHO-CHOICE: World Health Organization CHOosing Interventions that are Cost-Effective

Abstract

Background: Economic evaluations of nutrition-sensitive agriculture (NSA) interventions are scarce, limiting assessment of their potential affordability and scalability.

Objective: We conducted cost-consequence analyses of three participatory video-based interventions of fortnightly women's group meetings using: 1) NSA videos; 2) NSA and nutrition-specific videos; or 3) NSA videos with a nutrition-specific Participatory Learning and Action (PLA) cycle.

Methods: Interventions were tested in a 32-month, four-arm cluster-randomized controlled trial, UPAVAN, in Keonjhar district, Odisha, India. Impacts were evaluated in children aged 0-23 months and their mothers. We estimated program costs using data collected prospectively from expenditure records of implementing and technical partners, and societal costs using expenditure assessment of households with a child aged 0-23 months and key informant interviews. Costs were adjusted for inflation, discounted, and converted to 2019 US$.

Results: Total program costs of each intervention ranged from US$272,121 to US$386,907. Program costs per pregnant woman or mother of a child aged 0-23 months were US$62 for

NSA videos, US$84 for NSA and nutrition-specific videos, and US$78 for NSA videos with PLA (societal costs: US$125, US$143, and US$122 respectively). Substantial shares of total costs constituted developing and delivering the videos and PLA (52-69%) and quality assurance (25-41%). Relative to control, children's minimum dietary diversity was higher in the intervention incorporating nutrition-specific videos (adjusted relative risk [95% CI] 1.19 [1.03, 1.37]) and PLA (1.27 [1.11, 1.46]). Relative to control, mothers' minimum dietary diversity was higher in NSA video (1.21 [1.01, 1.45]), and NSA with PLA (1.30 [1.10, 1.53]) interventions.

Conclusion: NSA videos with PLA can increase both maternal and child dietary diversity and has the lowest cost per unit increase in diet diversity. Building on investments made in developing UPAVAN, cost-efficiency at scale could be increased with less intensive monitoring, reduced start-up costs, and integration within existing government programs.

Trial registration: ISRCTN65922679

Key words: Nutrition-sensitive agriculture, Cost-consequence analysis, Participatory learning and action, Women's groups, Dietary diversity, Maternal and child nutrition, India.

Background

There is strong evidence on the impacts and cost-effectiveness of nutrition-specific interventions (1-4), particularly in settings with high undernutrition burdens such as India. However, to achieve the Sustainable Development Goal targets (5) to end hunger and undernutrition (SDG 2), multi-sectoral approaches are needed to address the underlying causes of undernutrition (6). In rural areas of low- and middle-income countries, where the burden of undernutrition is highest and smallholder farming provides a major source of

nutrition and income (7), the agriculture sector could provide 'nutrition-sensitive' interventions that simultaneously increase both nutrition and agriculture outcomes.

Trials of nutrition-sensitive agriculture (NSA) interventions have shown that they can increase dietary outcomes, suggesting that their implementation at scale may be a policy option. Out of the eight trials that tested the effects of NSA interventions on children's minimum dietary diversity, four showed a significant increase, although neither of the two NSA trials measuring impacts on maternal dietary diversity showed an effect (8). However, our ability to recommend scale-up of NSA interventions is constrained by a lack of data on their costs, and therefore a lack of evidence on their value for money (6, 9, 10). So far, the few economic evaluations (the family of evaluation types that relate costs and impacts) of NSA interventions that do exist come from sub-Saharan Africa (10-12) – none come from South Asia (13, 14). Policymakers need this evidence to prioritize and justify their investments, particularly in resource-constrained settings in South Asia. Additionally, economic evaluations may be more needed for multi-sectoral interventions such as NSA, to garner support from the multiple (traditionally separate) sectors involved, and justify the efforts required in collaboration (15).

One reason for the lack of NSA economic evaluations is that traditional methods developed for single-sector interventions are unsuitable for multi-sectoral interventions. Cost-benefit analyses (which give cost per economic value of aggregate benefits) rely on too many assumptions to compute the economic value of dietary and agricultural outcomes. Cost-effectiveness analyses (which give costs per natural unit of an outcome) give misleadingly high estimates (16). For interventions designed to affect a range of outcomes, assigning all intervention costs to one outcome creates an erroneous impression that the cost per unit of improvement is prohibitively high. Cost-consequence analyses (where outcomes are reported alongside disaggregated costs) analyses offer a transparent approach that allows policymakers to weigh the evidence for themselves. Cost-consequence analyses are recommended for

multisectoral interventions with multiple health and non-health effects (17, 18), ideally alongside cost-effectiveness analysis.

This paper presents the economic evaluation results of the UPAVAN (Upscaling Participatory Action and Videos for Agriculture and Nutrition) trial, conducted in Odisha state, India, between 2016 and 2020 (8, 19). The trial aimed to test the nutritional and agricultural impacts of three video-based participatory NSA interventions, each compared to a control arm. The specific objectives of UPAVAN's economic evaluation were to: a) describe intervention coverage and participation, b) estimate the program cost and cost-efficiency (cost per participant) of implementing the interventions, c) estimate societal costs of the interventions, d) conduct a cost-consequence analysis to present the costs alongside the effects of the interventions and estimate cost per unit increase in outcome per intervention, e) examine effect of uncertain parameters, assumptions and potential scenarios on interventions' cost, and f) estimate the cost of delivering the interventions at scale and affordability of scale-up across rural Odisha.

Methods

Overview of the UPAVAN trial study design

A detailed description of the UPAVAN interventions, study design, and impacts is reported elsewhere (8, 19, 20). In brief, the UPAVAN trial was a four-arm, cluster randomized controlled trial, implemented in four administrative blocks (Patna, Keonjhar Sadar, Harichandanpur and Ghatgaon) in Keonjhar district, Odisha, India. One or two villages and surrounding hamlets were defined as a cluster, to ensure a minimum population of 800 per cluster. Stratified block randomization was used to allocate 148 clusters to four trial arms (three intervention arms and one control arm), giving 37 clusters per arm. Allocation of the clusters was stratified by distance to the nearest town (<10 km or ≥10 km) and the proportion of Scheduled Tribe or Scheduled Caste (historically disadvantaged) households (low (30%), medium (30-70%) and high (>70%)) (8, 19), giving six strata in total.

Study setting

Keonjhar district has an estimated population of 1.8 million, 86% of which is rural (21). Forty-four percent of Keonjhar's population belong to Scheduled Tribes and 12% to Scheduled Castes (21) – historically the most disadvantaged socio-economic groups in India. The prevalence of maternal and child undernutrition in Keonjhar is among the highest in India. In 2015-6, 30% of women (15-49 years of age) in Keonjhar were underweight and 40% were anemic (13). Over 40% of children aged under 5 years were stunted and 19% were wasted (13).

UPAVAN interventions

Interventions were implemented by the Voluntary Association for Rural Reconstruction and Appropriate Technology (VARRAT), a non-governmental organization in Odisha, with technical support from Digital Green, Ekjut, John Snow Inc. Research and Training Institute (JSI RTI), London School of Hygiene & Tropical Medicine (LSHTM), and University College London (UCL). The trial was evaluated by LSHTM, UCL, and DCOR Consulting Pvt. Ltd.

The three UPAVAN interventions have been described in detail elsewhere (19, 20) and are briefly described here, with an overview in **Figure 1**. Each intervention included two main components: a fortnightly women's group meeting (the content of which varied between interventions) and a follow-up home visit to group members after each meeting. The interventions worked with women's self-help groups (SHG) – an existing platform involved in savings and credit activities. The interventions were implemented for 32 months from March 2017 to October 2019.

Insert Figure 1

AGRI

In this arm, fortnightly women's groups viewed and discussed NSA videos, following a 'participatory video' approach designed by Digital Green (22). The participatory video approach had four steps: (1) local implementers identified relevant NSA practices to include in videos, (2) local videographers filmed farmers and other community members demonstrating or discussing the practices, (3) local facilitators screened the videos in group meetings and facilitated discussions, (4) facilitators conducted follow-up home visits to pregnant women and mothers of children aged 0–23 months who participated in the group meetings. NSA videos covered the main themes, following UPAVAN's theory of change (5, 19), of increasing production and diversity of nutritious or income-generating foods, increasing women's decision-making power in agricultural activities, and reducing pregnant and breastfeeding women's workloads.

Quality assurance and monitoring was embedded in the participatory video process. Facilitators kept registers to track attendance, whether participants were pregnant or had a child aged 0-23 months, and whether a government frontline health and nutrition care provider attended the meeting. During home visits, facilitators completed forms to record participants' adoption and/or recall of practices promoted in the previous meeting.

AGRI-NUT

This arm used the same participatory video approach as in AGRI, but videos covered both NSA and nutrition-specific topics. Groups received half of the NSA videos shown in the AGRI arm, and the other half were nutrition-specific videos covering topics on infant and young child feeding practices and maternal diets.

AGRI-NUT+PLA

This arm used the same participatory video approach as in AGRI, but integrated nutrition-specific meetings that followed a Participatory Learning and Action (PLA) approach (using

half the NSA videos shown in the AGRI arm; the other half were PLA meetings). In the PLA meetings, the groups followed a four-phase PLA cycle where they: 1) learned about and prioritized nutrition problems, 2) discussed and prioritized the causes, effects, and locally feasible strategies to address these problems, in their groups and with the wider community, 3) implemented the identified strategies, and 4) informally evaluated the results of their actions and made future plans. The PLA meetings were either interactive discussions without videos (using participatory techniques such as voting, storytelling, and games), or participatory videos on nutrition-specific topics that were developed as part of the PLA process. Therefore, nutrition-specific videos were different to those in the AGRI-NUT arm.

Control

Those in control arm (and intervention arms) received standard government services. In addition, the government frontline health and nutrition workers in all four arms received two days of training on maternal, infant, and young child nutrition.

Evaluating coverage and participation

Figure 2 describes the populations that the interventions aimed to include (intervention exposure) and benefit (intervention outcomes).

Insert Figure 2

The UPAVAN interventions were primarily designed to *include* pregnant women and mothers of children aged 0-23 months (primary intervention participants), and were primarily designed to *benefit* children aged 0-23 months, their mothers, and their households. Therefore, we primarily report coverage and cost-efficiency in terms of the former, and impacts (described in the next section) on the latter.

Coverage was assessed as whether or not primary intervention participants attended at least one group meeting and received at least one home visit, based on monitoring data recorded by group facilitators (registers with records on 46,327 meetings, and forms on 149,585 home

visits). We also assessed coverage in terms of all participating women, defined as women of any age who attended at least one group meeting according to group registers. This is because all women of all ages in the intervention clusters were eligible to participate in UPAVAN interventions, and the SHG platform that UPAVAN worked with includes women of all ages.

Participation is given as: total group meetings and home visits attended by primary intervention participants; group meetings attended by all women; and total 'points of contact' which is the sum of group meeting attendance (all women) and home visits.

Evaluating consequences (trial impacts)

We had two primary outcomes. The first was child dietary diversity, measured as the percentage of children aged 6-23 months consuming ≥4 out of 7 food groups in the previous 24-hours, using the WHO-defined food groups (23). The second was body-mass index (kg/m^2) of non-pregnant, non-postpartum (gave birth >42 days ago) mothers of these children. Secondary outcomes were maternal dietary diversity, measured as percentage of mothers consuming ≥5 out of 10 food groups in last 24-hours using FAO-defined food groups (24), and percentage of children with a weight-for-height z-score < -2 SD of the WHO growth standards median (25). The trial was powered for the two primary outcomes to give a target sample size of 4736 mother-child pairs (1184 per arm) at baseline and again at endline. Other outcomes on health, women's empowerment, food security, and agricultural production were pre-specified, and are given in **Supplemental Material Table S1**.

The impact of the interventions was evaluated on children aged 0–23 months and their mothers (and their households for household-level indicators). The impact evaluation used randomly selected samples of eligible households from each cluster at baseline and endline. Households were eligible if they contained a child aged 0-23 months with no disability affecting anthropometric measurements, and the child's primary caregiver had no disability impairing their participation in the surveys and had been resident in the household for at least half a year before data collection.

Impacts were analyzed using intention-to-treat analysis. The analyses were cross-sectional, assessing outcomes in each intervention arm compared to the control arm at endline. The analyses adjusted for baseline measures by including all individuals at each timepoint linked by cluster, and outcomes were analyzed using separate generalized estimating equations to account for clustering. Adjusted analyses also included distance to the nearest town and proportion of Scheduled Tribe or Scheduled Caste households as covariates.

Results of the UPAVAN impact evaluation are reported elsewhere (8). In this paper, we have presented adjusted effects on all pre-specified outcomes that were statistically significant from control; these comprise the 'consequences' in our cost-consequence analysis.

Evaluating costs

The full costing methodology is presented in the economic evaluation protocol (26), and is summarized in this section and **Figure 3**.

Insert Figure 3

Economic costs of the interventions were estimated from a program perspective (i.e., costs incurred by the implementing agencies) and a societal perspective (i.e. costs to program implementers, government health system, and program participants). Economic costs refer to direct financial costs plus indirect costs such as value of donated items or time (opportunity) costs of participating. All direct and indirect cost types, including program and societal costs, as well as the data sources and assumptions used for calculating costs, are given in **Supplemental Material Table S2.**

The time horizon for the costing was 41 months, including a 9-month start-up period and 32-months of intervention implementation. Activities during the start-up period included recruitment and training of group facilitators and their supervisors, community sensitization activities, and development of video content and PLA meeting plans.

Program costs

A combination of activity-based costing (27), expenditure approach, and ingredients approaches (28) were used to estimate program costs. First, the intervention components and associated main activities were identified and defined as cost centers. Then, data on quantity and costs (or estimated value of resources, in case of donated items) were collected and allocated to these cost centers. To estimate the direct costs of designing and implementing the interventions, we collected financial cost data from all UPAVAN partners' expenditure records or project accounts. For indirect costs, we identified donated items and volunteered time through interviews with all project staff, and estimated their opportunity cost (value) using the current market value for donated items (28-30) and staff monthly salaries for volunteered time. Donated items were mainly video-making and editing equipment used by the implementing partner. Volunteered time mainly included unpaid time contributed to design and adaptation of intervention materials, as well as quality assurance by technical partners.

Cost data were collected using data capture tools (**Supplemental Material-data collection tools**) designed for the project. All data collected were entered into a customized excel-based costing tool, adapted from the costing tool developed by UCL Centre for Global Health Economics (http://www.ighe.org) for analysis. The tool categorizes the costs based on the following line-items: staff, materials, capital, joint costs (shared by several activities such as field travel and partners' meetings) and overheads. It also categorizes costs by intervention component: AGRI, NUT, PLA, training of government frontline health and nutrition care providers, quality assurance and monitoring, or partner coordination; and implementation stage: start-up or implementation. Staff costs were allocated to intervention components using data from staff time-use surveys collected through interviews with all project staff (full descriptions of line items, intervention components, and implementation phases are given in **Supplemental Material Table S3**). The same allocation rule was applied to allocate non-staff joint costs to intervention components. Capital costs were annualized based on the

estimated lifetime of each item, using a discount rate of 3%. We included contributions of the international technical (JSI RTI) and research partners (LSHTM and UCL) in developing and supporting interventions, but not research costs.

Costs to government health system

We measured direct financial costs and indirect opportunity costs incurred by primary health centers and government frontline health and nutrition care providers (i.e., Anganwadi workers (AWWs), Accredited Social Health Activists (ASHAs) and Auxiliary Nurse Midwives (ANMs)).

Direct costs were based on any increase in the use of health and nutrition services (in the past 6 months), as determined by comparing percentage of households using any health or nutrition services in each intervention relative to control in the endline survey, and published data on unit cost to health centers for providing those services (31-36).

We estimated the indirect costs as the opportunity costs of government frontline health and nutrition care providers participating in the interventions. We calculated this based on group attendance by government frontline health and nutrition workers (assessed from facilitators' registers), mean duration of meetings and mean travel time to meeting location (from the endline survey), and published monthly salaries of the government frontline health and nutrition care providers (**Supplemental Material Table S2**).

Costs to participants and their households

We estimated opportunity costs to participants of attending dissemination meetings and follow-up home visits using: data on the total number of group attendants and follow-up home visits per intervention arm (from facilitators' registers and home visit forms); mean duration of group meetings, home visits, and mean travel time to the meeting location (collected in the UPAVAN endline survey); and the minimum daily wage of an agricultural

worker in Odisha state (303 Indian Rupees or US$4.31) (37) (**Supplemental Material Table S2**).

We estimated cost to households of adopting practices promoted in UPAVAN as any differences in expenditures on: seeking healthcare (out-of-pocket fees and transport costs paid for child and maternal healthcare from public, private, or informal healthcare providers), agricultural inputs, food, and non-food costs. These costs were estimated as the mean differences between each intervention and the control arm, using the expenditure survey in the UPAVAN endline survey.

Analysis

Our results are presented the in the form of cost-consequence analysis, by tabulating disaggregated costs and outcomes of the interventions compared to the control arm. We selected a program perspective as the base case to reflect the potential budget impact of adopting the intervention. The societal perspective presents the full costs of implementing the interventions.

All costs, including unit costs obtained from published studies, were adjusted for inflation using the Indian Consumer Price Index (38) and converted to 2019 US$, using the exchange rate of 70.42 (39) for the costs to Indian partners (in Indian Rupees, INR), and 0.78 (39) for costs to the UK partners (in British Pounds Sterling, GBP). In addition, costs were discounted at 3% per year, as recommended by WHO-CHOICE (World Health Organization CHOosing Interventions that are Cost-Effective) (40) and the Gates/iDSI Reference Case for Economic Evaluation (41). Our study follows the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) (42).

We calculated total costs and mean annual costs of the interventions. Mean annual costs enable comparisons with other interventions that run for different durations. Mean annual costs were calculated as the sum of start-up and implementation costs, divided by 41 months (the costing time horizon) and multiplied by 12, so they divide start-up costs equally across

each year. We decomposed the total costs of the interventions and presented these as a share of line-item (i.e. staff, materials, capital, other), intervention component (i.e. NSA videos, nutrition-specific videos, PLA, quality assurance, coordination, frontline worker training), and implementation phase (i.e. start-up and implementation).

To estimate 'cost-efficiency' of the interventions, we calculated the total or annual costs of each intervention per primary intervention participant. We also estimated cost per total point of contact (sum of group attendees and total home visits). We also estimated cost per unit increase in maternal and child dietary diversity scores (i.e. two statistically significant primary and secondary outcomes) for each intervention arm, compared to the control arm. They were calculated as mean increase in outcome divided by cost per primary intervention participant.

We conducted a number of univariate sensitivity analyses that vary one parameter at a time, and scenarios for potential intervention costs at scale. In sensitivity analysis, we examined the impact of two uncertain assumptions: we altered the allocation rule for dividing the costs of the nutrition-specific component between the AGRI-NUT and AGRI-NUT+PLA arms (from a 75:25 rule to a 90:10 rule), and we varied the discount rate from 0% to 6% (40, 41). In scenario analyses, we tested impact of three scenarios that we believe will be relevant when interventions are implemented at scale: reducing start-up costs by 50%; reducing costs of monitoring by 25% and 50%; and replacing international staff costs with local staff costs. A detailed description of sensitivity and scenario analyses are presented in **Supplementary Material**.

Finally, we estimated potential cost of delivering the AGRI-NUT+PLA intervention to all rural populations in Odisha state, by dividing the total intervention cost by the total population in the intervention clusters (based on census data) and multiplying by the total rural population of Odisha.

Results

Trial coverage and participation

UPAVAN's coverage and participation is described in **Table 1**. Throughout the 32-month implementation period, the UPAVAN interventions covered a mean of 4,567 primary intervention participants, and 9,367 women of any age, per intervention arm. So, around half of participants were pregnant women and mothers of children aged 0-23 months, and 17% of the total population directly participated in UPAVAN intervention activities, per arm. Assuming an average of five members per household (and one participant per household, and household members discussed the interventions), the interventions reached a mean of 87% of the total population per arm.

Insert Table 1

Program costs and program cost-efficiency

Program costs are described in **Table 2** and presented by year in **Supplemental Material Table S4**. Total program costs of the AGRI, AGRI-NUT and AGRI-NUT+PLA intervention arms were estimated as US$272,121, US$366,686 and US$386,907 respectively, and the mean annual costs of the intervention arms were estimated as US$79,645, US$107,323 and US$113,241, respectively. Start-up costs accounted for around 26% of total costs, with the AGRI-NUT arm having the highest proportion of start-up costs (30%) and AGRI-NUT+PLA arm having the lowest (23%). The main reason for higher start-up costs for AGRI-NUT arm is that more staff time was spent preparing nutrition-specific videos and training, mainly driven by inputs from international staff.

Insert Table 2

The main intervention activities of video production, group meetings, and follow-up home visits constituted the largest share of total costs (ranging from 52% in AGRI-NUT+PLA to 69% in AGRI). This was followed by the quality assurance and monitoring activities (ranging

from 25% in the AGRI arm to 41% in the AGRI-NUT+PLA arm) (**Figure 4**). In the AGRI-NUT+PLA arm, more staff time was spent on the quality assurance of the PLA component from one partner (Ekjut).

Insert Figure 4

Decomposing the total program costs to line-items or inputs (as given in **Table 3**) shows that staff costs constituted most costs, at around 60% in each intervention arm, ranging from 56% in the AGRI-NUT arm to 65% in the AGRI-NUT+PLA arm. This was followed by other recurrent costs (travel costs and office overheads), varying from 29% in the AGRI-NUT+PLA arm to 39% in the AGRI-NUT, mainly due to large portion of international travel by international staff (JSI RTI) in the AGRI-NUT arm. Most staff costs related to the delivery of interventions, i.e., salary for 24-26 facilitators per arm and 2-3 supervisors per arm, followed by support provided by technical assistance and research partners (**Supplemental Figure 1**). International staff costs were around 33% of total staff costs, and mostly contributed to intervention development and technical support during implementation, particularly in the AGRI-NUT arm (**Supplemental Figure 1**).

Insert Table 3

Table 4 gives the cost per intervention from both program and societal perspectives, followed by the cost-efficiency estimates per primary participant and per point of contact. Program costs per primary intervention participant were US$62 in the AGRI arm, US$84 in the AGRI-NUT arm, and US$78 in the AGRI-NUT+PLA arm. Program cost per point of contact were US$0.64 in AGRI, US$0.92 in AGRI-NUT, and US$1.17 in AGRI-NUT+PLA.

Insert Table 4

Societal costs of the interventions

Interventions slightly increased the use of maternal care services (such as delivery care, on-site feeding, and malaria testing) delivered by government frontline nutrition and health care

providers, but participants did not incur significantly higher out-of-pocket expenditures. Based on the unit cost of these services, the total cost to the health system of this increased demand for health services ranged from US$1,680 in the AGRI-NUT arm to US$7,793 in the AGRI (**Table 4**).

Overall, government frontline nutrition and health care workers attended 9,388 (in AGRI), 9,509 (in AGRI-NUT) and 8,012 (in AGRI-NUT+PLA) group meetings. Estimated total opportunity costs of their involvement ranged from US$3,326 in the AGRI-NUT+PLA arm to US$4,174 in the AGRI-NUT arm (**Table 4**).

Analyses of the endline survey data showed no evidence that the interventions increased participant households' expenditures in total, on healthcare, agricultural inputs, food, or non-food items (8). The estimated opportunity costs to the intervention participants from time spent participating ranged from US$209,433 in the AGRI-NUT+PLA arm to US$266,228 in the AGRI arm.

Taken together, total societal costs of the AGRI, AGRI-NUT and AGRI-NUT+PLA interventions were US$549,668, US$621,355 and US$604,762, respectively. Total cost efficiency (program and societal costs per pregnant woman or mother of children aged 0-23 months) was US$125 in AGRI, US$143 in AGR-NUT, and US$122 in AGRI-NUT+PLA. Total societal cost per point of contact was US$1.29, US$1.55, and US$1.82 respectively (**Table 4**).

Intervention consequences and cost-outcome results

Results in **Table 5** show that the AGRI-NUT and AGRI-NUT+PLA interventions increased children's minimum dietary diversity, each compared to the control (adjusted relative risk [95% CI] 1.19 [1.03, 1.37]; 1.27 [1.11, 1.46]). Both AGRI and AGRI-NUT+PLA increased mothers' minimum dietary diversity, each compared to the control (adjusted relative risk [95% CI] AGRI: 1.21 [1.01, 1.45]; AGRI-NUT+PLA 1.30 [1.10, 1.53]). Furthermore, the AGRI intervention increased women's decision-making, and the total and net annual value of

agricultural production compared to the control arm. There was no statistically significant effect of the interventions on the other outcomes (8).

Insert Table 5

Table 6 presents results from our estimates for cost per mean change in maternal and child dietary diversity scores. The results show that the AGRI-NUT+PLA arm has the lowest cost per unit of improvement with US$287, reflecting its larger improvements in both maternal and child dietary diversity than AGRI and AGRI-NUT arms, both compared to the control arm.

Insert Table 6

Sensitivity and scenario analysis

Table 7 shows that replacing international staff costs with local staff costs and reducing monitoring and start-up costs had a large impact on the results. Replacing international staff costs with local staff costs reduced total costs by between 24% in the AGRI-NUT+PLA arm to 40% in the AGRI-NUT arm. Reducing costs of the monitoring information system by 50% (25%), reduced the total costs by between 13% (6%) in the AGRI arm to 21% (10%) in the AGRI-NUT+PLA arm. Reducing start-up costs by 50% reduced the total costs and cost per primary intervention participant (pregnant women and mothers of children 0-23 months of age) by between 12% in the AGRI-NUT+PLA arm to 15% in the AGRI-NUT arm. Varying the discount rate or changing the allocation rule for the nutrition-specific component had a modest effect on the results, ranging from -10 to +10%.

Insert Table 7

Cost and affordability of scale-up

Given that AGRI-NUT+PLA was the only intervention to increase both maternal and child dietary diversity, we model the potential cost of scaling up the AGRI-NUT+PLA intervention

to all rural districts in Odisha. The cost would be around US$65 million per year, based on a cost of US$1.9 per person (total population in the AGRI-NUT+PLA intervention clusters). This is approximately 5% of the proposed state health budget for 2021-2022 (around US$1.3 billion per year) or 1.7% of the combined health and agriculture budget (43). However, unit costs might be lower due to potential economies of scale. In addition, given the investments already made in developing the UPAVAN interventions, it is expected that monitoring and evaluation, start-up, and coordination activities will be less intensive at scale, reducing implementation costs significantly, as shown in the sensitivity and scenario analyses.

Discussion

This study contributes to the limited economic evaluation evidence on multisectoral nutrition interventions and is the first economic evaluation of a nutrition-sensitive agriculture intervention in South Asia. We found that participatory NSA interventions, with different combinations of nutrition-specific behavior change or PLA components, can increase child and maternal minimum dietary diversity. The total costs of designing and implementing the UPAVAN interventions ranged from US$271,121 to US$386,907 and annual costs ranged from US$79,645 to US$113,241. Throughout the 32 months of implementation, the interventions covered a mean of 4567 pregnant women and mothers of children 0-23 months of age per intervention, and the cost per pregnant woman or mother (the primary intervention participant) ranged from US$62 in the AGRI arm to US$84 in the AGRI-NUT arm.

Comparison between UPAVAN and other NSA interventions is challenging due to differences in intervention components, delivery platforms, scale, outcomes assessed, and costing approaches. However, two interventions share some similarities with the UPAVAN interventions: NEEP-IE (the Nutrition Embedded Evaluation Programme Impact Evaluation) in Malawi (11, 12, 44), and Mama SASHA (Sweetpotato Action for Security and Health in Africa) in Kenya (10). NEEP-IE integrated NSA with nutrition-specific training and used community-based early childhood development centers and parenting group platforms (44,

45). Mama SASHA promoted production and consumption of orange-fleshed sweet potato and integrated nutrition-specific and health components, delivered through health facilities, community health workers, and extension officers (46). UPAVAN, NEEP-IE and Mama Sasha had similar cost-efficiency, at US$62 to US$84 per participant in UPAVAN, US$160 per pre-school child covered in NEEP-IE (11), and US$110 per woman and child covered in Mama SASHA (10). In all three, staff and travel costs constituted major shares (UPAVAN: 56-60%; NEEP-IE: 40%; Mama SASHA: 25%). Comparing point estimates we find that, for child dietary diversity, AGRI and AGRI-NUT was less cost-effective than NEEP-IE and Mama SASHA, but AGRI-NUT+PLA was more cost-effective (AGRI had no effect; cost per food group increase for: AGRI-NUT US$ 603; NEEP-IE US$ 444; Mama SASHA US$ 305; AGRI-NUT+PLA US$ 278). Similarly, AGRI and AGRI-NUT were less cost-effective than Mama SASHA at improving maternal diet diversity, but AGRI-NUT+PLA was more cost-effective (cost per food group increase for: AGRI US$ 517; AGRI-NUT US$ 603; Mama SASHA US$ 324; AGRI-NUT+PLA US$ 325) (47). NEEP-IE did not report effects on maternal diet diversity.

Taken together, we show broadly similar cost profiles, cost-efficiency, and cost-effectiveness for UPAVAN, NEEP-IE and Mama SASHA. Although the UPAVAN trial was not designed to detect differences between intervention arms, we note that the higher cost-effectiveness in AGRI-NUT+PLA intervention, compared to the control arm, might suggest that AGRI-NUT+PLA intervention is better value for money than the AGRI, AGRI-NUT interventions. Therefore, the Participatory Learning and Action component may help to increase cost-effectiveness of NSA interventions. The choice of which intervention to scale up will depend on transferability of intervention models across contexts, and policymakers' priorities for other outcomes. For example, NEEP-IE had additional effects on stunting (with cost-effectiveness ratios of US$595 per case of stunting averted, and US$516 per DALY averted (12)), and both NEEP-IE and AGRI interventions increased agricultural production, whereas

Mama SASHA specifically increased production of orange-flesh sweet potatoes and nutrition knowledge.

We consider how NSA interventions compare to other nutrition-specific interventions, beyond the 10 nutrition-specific interventions already recommended at scale (at a cost of US$125 to US$571 per life-year saved). Nutrition-specific women's groups using a PLA approach (48) and SHG (49) have shown similar cost-efficiency (US$62 to US$140 per participant), and similar magnitude of effects on dietary diversity of mothers (adjusted odds ratio >5/10 food groups: 1.4 (48)), and children (mean difference: 0.17 food groups (49)). Biofortification with nutrition education is less expensive, at US$ 65 and US$ 49 per beneficiary household in Mozambique and Uganda respectively, and can double vitamin A intakes in children (50). A modelling study of food-based interventions showed that, in India, mass media campaigns and complementary food processing interventions would be more cost-effective than a household horticulture intervention (US$ 90 and US$ 41, versus US$ 644 US$ per life-year saved)(51).

We conclude that NSA interventions have similar cost-efficiency and effectiveness to nutrition-specific women's group interventions but may be less cost-effective at improving nutrition than other approaches such as mass media campaigns, complementary food processing, and food fortification. However, NSA can have added benefits of improved agricultural productivity, which nutrition-specific interventions would be less likely to achieve. In contrast, adding agricultural components, such as home-gardens (52) or community vegetable gardens (53), to nutrition or health education interventions are prohibitively expensive, at around 2014 US$918 per beneficiary in Bangladesh (52) and EUR 1,525 per beneficiary household in Zimbabwe (53).

Policy implications: Scalability and affordability

Before we conducted the trial, some components of the UPAVAN interventions were already being implemented at scale in several states in India. Participatory agriculture extension

videos have been scaled up across several states in India, in collaboration with National and State Livelihood Missions and using a women's self-help group platform, reaching around two million smallholder farmers (54). Participatory nutrition-specific videos have been scaled up across five states, in collaboration with State Livelihood Missions, the National Health Mission and other state-level institutions, reaching around half a million pregnant women and mothers of children aged 0-23 months (55). In addition, supported by the National Health Mission, PLA groups have been scaled up across all districts in Jharkhand and a third of districts in Madhya Pradesh states, through incentivized ASHAs and ASHA supervisors (56, 57). Evidence on state-wide scale-up of PLA groups in Jharkhand showed that employing incentivized ASHAs and ASHA supervisors, and using an innovative approach for training at scale, resulted in a substantial reduction in implementation costs, without compromising the impact of the intervention (58, 59). Similar models could be tested for participatory video-based NSA interventions.

Although there is clearly policy interest in the UPAVAN components, their implementation at scale is currently only being conducted by government frontline workers from single sectors. Scale-up of the UPAVAN interventions and other multisectoral approaches will require coordination of multiple stakeholders across sectors, and the challenges of this are well recognized (12). It is hoped that our economic evaluation will provide further impetus to increase collaboration across sectors, but stakeholder analyses may be needed to support this further.

Limitations

Some limitations are noted. First, adoption of practices promoted by the UPAVAN interventions, or collective actions taken by participating communities might have caused direct and indirect costs and benefits to participants and the communities that were not accounted for. As with any complex economic evaluation, it is difficult to determine the direction of bias in our overall conclusions because it was also not possible to fully identify

and measure all of the benefits associated with these interventions. The trial only measured effects on children 0-23 months of age and their mothers and families, and not the communities as a whole. They also did not include other possible short- and long-term consequences for participants, such as improved soil quality, micronutrient adequacy, intra-household relationships, social support, mental health, or overall wellbeing. Second, some community members and government frontline health and nutrition care workers were involved in the production of NSA and nutrition-specific videos. The costs of their involvement have not been included here but they are likely to be small and would not seriously affect the study findings. Third, as is standard practice, the trial was powered to detect differences only in the primary outcomes. Statistically insignificant effects in other outcomes such as household food expenditures, healthcare seeking or utilization could be due to lack of statistical power rather than lack of effect. Finally, we do not report cost-effectiveness in terms of outcomes commonly used in cost-effectiveness analyses of nutrition interventions (such as Disability Adjusted Life Years, or life-years saved). This is because they were not outcomes that the interventions aimed to change, but it does limit comparison with other nutrition interventions.

Conclusion

This study estimated the cost of designing and implementing three participatory NSA interventions in rural India, responding to the gap in evidence on the costs of multisectoral NSA interventions, and providing useful data to inform their potential scale-up. Our findings show that the costs per primary intervention participant of implementing the interventions are comparable with the results from a limited set of evaluated multisectoral NSA interventions. Considering that substantial investment has already been made to develop the UPAVAN interventions, costs at scale could be reduced with a less intensive monitoring information system, reduced start-up costs, integration within existing programs, and possible economies of scale. We recommend scale-up of AGRI-NUT+PLA, which had the lowest cost per unit increase in dietary diversity. This should be feasible, given that participatory videos on

agriculture, nutrition, and PLA groups are already being implemented at scale in several

settings, and because the intervention approach is designed to be responsive to local contexts.

References

1.   Bhutta ZA, Das JK, Rizvi A, Gaffey MF, Walker N, Horton S, Webb P, Lartey A, Black RE, Lancet Nutrition Interventions Review Group tM, et al. Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? Lancet. 2013;382(9890):452-77. doi: 10.1016/S0140-6736(13)60996-4. PubMed PMID: 23746776.

2.   Gyles CL, Lenoir-Wijnkoop I, Carlberg JG, Senanayake V, Gutierrez-Ibarluzea I, Poley MJ, Dubois D, Jones PJ. Health economics and nutrition: a review of published evidence. Nutr Rev. 2012;70(12):693-708. doi: 10.1111/j.1753-4887.2012.00514.x. PubMed PMID: 23206283.

3.   Ramponi F, Tafesse W, Griffin S. Economic evaluation of interventions to address undernutrition: a systematic review. Health Policy Plan. 2021;36(4):533-41. Epub 2020/12/07. doi: 10.1093/heapol/czaa149. PubMed PMID: 33280036; PubMed Central PMCID: PMCPMC8128006.

4.   Njuguna RG, Berkley JA, Jemutai J. Cost and cost-effectiveness analysis of treatment for child undernutrition in low- and middle-income countries: A systematic review. Wellcome Open Res. 2020;5:62. Epub 2020/10/29. doi: 10.12688/wellcomeopenres.15781.2. PubMed PMID: 33102783; PubMed Central PMCID: PMCPMC7569484.

5.   United Nations. SDG2: Zero Hunger. Available from: https://www.un.org/sustainabledevelopment/hunger/.

6.   Ruel MT, Alderman H, Maternal, Group CNS. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? The Lancet. 2013;382(9891):536-51.

7.   2020 Global Nutrition Report.Inequalities of the global burden of malnutrition. . 2020.

8.   Kadiyala S, Harris-Fry H, Pradhan R, Mohanty S, Padhan S, Rath S, James P, Fivian E, Koniz-Booher P, Nair N, et al. Effect of nutrition-sensitive agriculture interventions with participatory videos and women's group meetings on maternal and child nutritional outcomes in rural Odisha, India (UPAVAN trial): a four-arm, observer-blind, cluster-randomised controlled trial. The Lancet Planetary Health. 2021. doi: 10.1016/S2542-5196(21)00001-2.

9.   Ruel MT, Quisumbing AR, Balagamwala M. Nutrition-sensitive agriculture: What have we learned so far? Glob Food Secur-Agr. 2018;17:128-53. doi: 10.1016/j.gfs.2018.01.002. PubMed PMID: WOS:000436598300015.

10.   Levin CE, Self JL, Kedera E, Wamalwa M, Hu J, Grant F, Girard AW, Cole DC, Low JW. What is the cost of integration? Evidence from an integrated health and agriculture project to improve nutrition outcomes in Western Kenya. Health Policy Plan. 2019;34(9):646-55. Epub 2019/09/11. doi: 10.1093/heapol/czz083. PubMed PMID: 31504504; PubMed Central PMCID: PMCPMC6880337.

11.   Margolies A, Gelli A, Daryanani R, Twalibu A, Levin C. When Communities Pull Their Weight: The Economic Costs of an Integrated Agriculture and Nutrition Home-Grown Preschool Meal Intervention in Malawi. Food Nutr Bull. 2021;42(1):3-22. Epub 2021/04/22. doi: 10.1177/0379572120986693. PubMed PMID: 33878905; PubMed Central PMCID: PMCPMC8129463.

12.   Gelli A, Kemp Cg, Margolies A, Twalibu A, Katundu M, C. L. Economic evaluation of an early childhood development center–based agriculture and nutrition intervention in Malawi. Food Security. 2021. doi: 10.1007/s12571-021-01203-6.

13.   NFHS-4. National Family Health Survey, India. In: International Institute for Population Sciences(IIPS) M, India; ORC Macro, Calverton, Maryland, USA; East-West Center, Honolulu, Hawaii, USA. , editor. 2016.

14.   Avula R, Raykar N, Menon P, Laxminarayan R. Reducing stunting in India: what investments are needed? Maternal & child nutrition. 2016;12(S1):249-52.

15.   Gaihre S, Kyle J, Semple S, Smith J, Marais D, Subedi M, Morgan H. Bridging barriers to advance multisector approaches to improve food security, nutrition and population health in Nepal: transdisciplinary perspectives. BMC Public Health. 2019;19(1):961. doi: 10.1186/s12889-019-7204-4.

16.   Levin C, Masters W, Gelli A, Harris-Fry H, Kadiyala S, Kalamatianou S, Low J, Puett C, Skordis-Worrall J, Vosti S. Economic evaluation of multisectoral actions for health and nutrition. Agriculture, Nutrition and Health Academy Working Group of Economic Evaluations. 2019.

17.   NICE. How NICE Measures Value for Money in Relation to Public Health Interventions. London: NICE (www.nice.org.uk) 2013.

18.   Drummond MF, Sculpher MJ, Claxton K, Stoddart GL, Torrance GW. Methods for the economic evaluation of health care programmes: Oxford university press; 2015.

19.   Kadiyala S, Prost A, Harris-Fry H, O'Hearn M, Pradhan R, Pradhan S, Mishra NK, Rath S, Nair N, Rath S, et al. Upscaling Participatory Action and Videos for Agriculture and Nutrition (UPAVAN) trial comparing three variants of a nutrition-sensitive agricultural extension intervention to improve maternal and child nutritional outcomes in rural Odisha, India: study protocol for a cluster randomised controlled trial. Trials. 2018;19(1):176. doi: 10.1186/s13063-018-2521-y. PubMed PMID: 29523173; PubMed Central PMCID: PMCPMC5845188.

20.   Harris-Fry H, O'Hearn M, Pradhan R, Krishnan S, Nair N, Rath S, Rath S, Koniz-Booher P, Danton H, Aakesson A, et al. How to design a complex behaviour change intervention: experiences from a nutrition-sensitive agriculture trial in rural India. BMJ Glob Health. 2020;5(6). Epub 2020/06/10. doi: 10.1136/bmjgh-2020-002384. PubMed PMID: 32513863; PubMed Central PMCID: PMCPMC7282327.

21.   India Co. Census of India 2011, Odisha, District Census Handbook, Kendujhar, Village and Town Wise Primary Census Abstract (PCA). In: Orissa DoCOi, editor. Odisha2011.

22.   Gandhi R, Veeraraghavan R, Toyama K, Ramprasad V. Digital Green: Participatory video and mediated instruction for agricultural extension. Inf Technol Int Dev. 2009;5(1):1-15.

23.   WHO. Indicators for assessing infant and young child feeding practices: definitions and measurement methods. World Health Organization, 2021.

24.   FAO and FHI 360. Minimum Dietary Diversity for Women:A Guide for Measurement. Rome: the Food and Agriculture Organization of the United Nations, 2016.

25.   WHO and UNICEF. WHO child growth standards and the identification of severe acute malnutrition in infants and children: A Joint Statement. 2009.

26.   Haghparast-Bidgoli H, Skordis J, Harris-Fry H, Krishnan S, O'Hearn M, Kumar A, Pradhan R, Mishra NK, Upadhyay A, Pradhan S, et al. Protocol for the cost-consequence and equity impact analyses of a cluster randomised controlled trial comparing three variants of a nutrition-sensitive agricultural extension intervention to improve maternal and child dietary diversity and nutritional status in rural Odisha, India (UPAVAN trial). Trials. 2019;20(1):287. Epub 2019/05/28. doi: 10.1186/s13063-019-3388-2. PubMed PMID: 31133067; PubMed Central PMCID: PMCPMC6537168.

27.   Fiedler JL, Villalobos CA, De Mattos AC. An activity-based cost analysis of the Honduras community-based, integrated child care (AIN-C) programme. Health Policy Plan. 2008;23(6):408-27. doi: 10.1093/heapol/czn018. PubMed PMID: 18755734.

28.   Johns B, Baltussen R, Hutubessy R. Programme costs in the economic evaluation of health interventions. Cost Eff Resour Alloc. 2003;1(1):1. PubMed PMID: 12773220; PubMed Central PMCID: PMCPMC156020.

29.   Hutton G, Baltussen R. Cost valuation in resource-poor settings. Health Policy Plan. 2005;20(4):252-9. doi: 10.1093/heapol/czi025. PubMed PMID: 15965037.

30.   Walker D. Cost and cost-effectiveness guidelines: which ones to use? Health Policy Plan. 2001;16(1):113-21. PubMed PMID: 11238438.

31.   Sethi V, Tiwari K, Sareen N, Singh S, Mishra C, Jagadeeshwar M, Sunitha K, Kumar SV, de Wagt A, Sachdev HPS. Delivering an Integrated Package of Maternal Nutrition Services in Andhra Pradesh and Telangana (India). Food Nutr Bull. 2019;40(3):393-408. Epub 2019/06/18. doi: 10.1177/0379572119844142. PubMed PMID: 31204503.

32.   Engel N, Ganesh G, Patil M, Yellappa V, Vadnais C, Pai NP, Pai M. Point-of-care testing in India: missed opportunities to realize the true potential of point-of-care testing programs. BMC Health Serv Res. 2015;15:550. Epub 2015/12/15. doi: 10.1186/s12913-015-1223-3. PubMed PMID: 26652014; PubMed Central PMCID: PMCPMC4677441.

33.   Menon P, McDonald CM, Chakrabarti S. Estimating the cost of delivering direct nutrition interventions at scale: national and subnational level insights from India. Matern Child Nutr. 2016;12 Suppl 1:169-85. Epub 2016/05/18. doi: 10.1111/mcn.12257. PubMed PMID: 27187914; PubMed Central PMCID: PMCPMC6680110.

34.   Prinja S, Bahuguna P, Mohan P, Mazumder S, Taneja S, Bhandari N, van den Hombergh H, Kumar R. Cost Effectiveness of Implementing Integrated Management of Neonatal and Childhood Illnesses Program in District Faridabad, India. PLoS One. 2016;11(1):e0145043. Epub 2016/01/05. doi: 10.1371/journal.pone.0145043. PubMed PMID: 26727369; PubMed Central PMCID: PMCPMC4699694.

35.   Prinja S, Gupta A, Verma R, Bahuguna P, Kumar D, Kaur M, Kumar R. Cost of Delivering Health Care Services in Public Sector Primary and Community Health Centres in North India. PLoS One. 2016;11(8):e0160986. Epub 2016/08/19. doi: 10.1371/journal.pone.0160986. PubMed PMID: 27536781; PubMed Central PMCID: PMCPMC4990301.

36.   Prinja S, Jeet G, Verma R, Kumar D, Bahuguna P, Kaur M, Kumar R. Economic analysis of delivering primary health care services through community health workers in 3 North Indian states. PLoS One. 2014;9(3):e91781. Epub 2014/03/15. doi: 10.1371/journal.pone.0091781. PubMed PMID: 24626285; PubMed Central PMCID: PMCPMC3953597.

37.   Minimum Wage – Odisha 2020. Available from: https://paycheck.in/salary/minimumwages/19709-odisha/19710-agriculture.

38.   World Bank. Consumer Price Index: World Bank; 2020 [cited 2020 29/05/2020]. Available from: https://data.worldbank.org/indicator/FP.CPI.TOTL?locations=IN.

39.   Bank W. Official exchange rate 2020 [cited 2020 29/05/2020]. Available from: https://data.worldbank.org/indicator/PA.NUS.FCRF.

40.   Tan-Torres Edejer T, Baltussen R, Adam T, Hutubessy R, Acharya A, Evans DB, CJ. M. Making choices in health: WHO guide to cost-effectiveness analysis. Geneva: World Health Organization; 2003.

41.   Claxton K, Revill P, Sculpher M, Wilkinson T, Cairns J, Briggs A. The Gates Reference Case for Economic Evaluation. The Bill and Melinda Gates Foundation, 2014.

42.   Husereau D, Drummond M, Petrou S, Carswell C, Moher D, Greenberg D, Augustovski F, Briggs AH, Mauskopf J, Loder E, et al. Consolidated Health Economic Evaluation Reporting Standards (CHEERS)--explanation and elaboration: a report of the

ISPOR Health Economic Evaluation Publication Guidelines Good Reporting Practices Task Force. Value Health. 2013;16(2):231-50. doi: 10.1016/j.jval.2013.02.002. PubMed PMID: 23538175.

43.   Odisha Government. Odisha budget: Finance Department, Odisha Government; 2021 [cited 2021 16/04/2021]. Available from: https://budget.odisha.gov.in/previous-yearly-budget/2021.

44.   Gelli A, Nguyen PH, Santacroce M, Twalibu A, Margolies A, Katundu M. A Community-Based Early Childhood Development Center Platform Promoting Diversified Diets and Food Production Increases the Mean Probability of Adequacy of Intake of Preschoolers in Malawi: A Cluster Randomized Trial. J Nutr. 2020;150(2):350-5. Epub 2019/10/17. doi: 10.1093/jn/nxz245. PubMed PMID: 31616933.

45.   Gelli A, Margolies A, Santacroce M, Roschnik N, Twalibu A, Katundu M, Moestue H, Alderman H, Ruel M. Using a Community-Based Early Childhood Development Center as a Platform to Promote Production and Consumption Diversity Increases Children's Dietary Intake and Reduces Stunting in Malawi: A Cluster-Randomized Trial. J Nutr. 2018;148(10):1587-97. Epub 2018/09/12. doi: 10.1093/jn/nxy148. PubMed PMID: 30204916; PubMed Central PMCID: PMCPMC6168702.

46.   Cole DC, Levin C, Loechl C, Thiele G, Grant F, Girard AW, Sindi K, Low J. Planning an integrated agriculture and health program and designing its evaluation: Experience from Western Kenya. Eval Program Plann. 2016;56:11-22. Epub 2016/03/24. doi: 10.1016/j.evalprogplan.2016.03.001. PubMed PMID: 27003730; PubMed Central PMCID: PMCPMC4863223.

47.   Low J. Integrating health and agriculture to maximize the nutritional impact of orange-fleshed sweetpotato: Results from the Mama SASHA. Nairobi (Kenya): International Potato Center (CIP), 2015.

48.   Nair N, Tripathy P, Sachdev HS, Pradhan H, Bhattacharyya S, Gope R, Gagrai S, Rath S, Rath S, Sinha R, et al. Effect of participatory women's groups and counselling through home visits on children's linear growth in rural eastern India (CARING trial): a cluster-randomised controlled trial. Lancet Glob Health. 2017;5(10):e1004-e16. Epub 2017/09/16. doi: 10.1016/S2214-109X(17)30339-X. PubMed PMID: 28911749; PubMed Central PMCID: PMCPMC5640793.

49.   Gupta S, Kumar N, Menon P, Pandey S, and Raghunathan K. Engaging women's groups to improve nutrition: Findings from an evaluation of the JEEViKA multisectoral convergence pilot in Saharsa, Bihar. Washington, DC: World Bank., 2019.

50.   de Brauw A, Eozenou P, Gilligan DO, Hotz C, Kumar N, Meenakshi JV. Biofortification, Crop Adoption and Health Information: Impact Pathways in Mozambique and Uganda. Am J Agric Econ. 2018;100(3):906-30. Epub 2018/01/01. doi: 10.1093/ajae/aay005. PubMed PMID: 32139914; PubMed Central PMCID: PMCPMC7053385.

51.   Webb P, Danaei G, Masters WA, Rosettie KL, Leech AA, Cohen J, Blakstad M, Kranz S, Mozaffarian D. Modelling the potential cost-effectiveness of food-based programs to reduce malnutrition. Global food security. 2021;29:100550.

52.   Schreinemachers P, Patalagsa MA, MN. U. Impact and cost-effectiveness of women's training in home gardening and nutrition in Bangladesh. Journal of Development Effectiveness. 2016;8(4):473–88.

53.   Puett C, Salpeteur C, Lacroix E, Zimunya SD, Israel AD, Ait-Aissa M. Cost-effectiveness of community vegetable gardens for people living with HIV in Zimbabwe. Cost Eff Resour Alloc. 2014;12:11. Epub 2014/05/17. doi: 10.1186/1478-7547-12-11. PubMed PMID: 24834014; PubMed Central PMCID: PMCPMC4022439.

54.   Green D. 2021 [cited 2021 01/04/2021]. Available from: https://www.digitalgreen.org/india/.

55.   Green D. SAMVAD project 2021 [cited 2021 01/04/2021]. Available from: https://www.digitalgreen.org/samvad/.

56.   EKJUT. http://www.ekjutindia.org/ 2021 [cited 2021 01/04/2021].

57.   National Health Mission. Annual Report. National Health Mission Department of Health & Family Welfare. , 2018.

58.   CIFF. SUSTAINABLE CHILD HEALTH SOLUTIONS: FOR THE COMMUNITY, BY THE COMMUNITY: Children Investment Fund Foundation; 2019 [cited 2021 20 Jan]. Available from: https://ciff.org/news/sustainable-child-health-solutions-community-community/.

59.   Nair N, Tripathy PK, Gope R, Rath S, Pradhan H, Rath S, Kumar A, Nath V, Basu P, Ojha A, et al. Effectiveness of participatory women's groups scaled up by the public health system to improve birth outcomes in Jharkhand, eastern India: a pragmatic cluster non-randomised controlled trial. BMJ Glob Health. 2021;6(11). Epub 2021/11/05. doi: 10.1136/bmjgh-2021-005066. PubMed PMID: 34732513; PubMed Central PMCID: PMCPMC8572384.
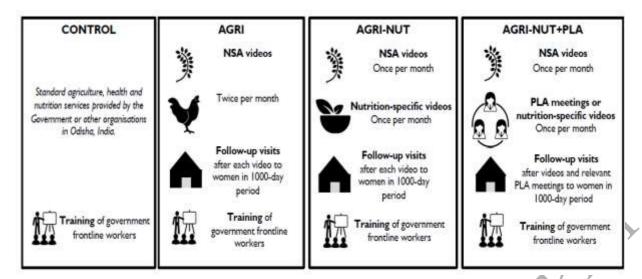
Figure legends

Figure 1: Overview of components delivered across UPAVAN interventions and control arms, adapted with permission from Kadiyala et al. (2018) (19).

Figure 2: Target populations of UPAVAN interventions

Figure 3: Conceptual framework for cost analysis of UPAVAN interventions, adapted with permission from Haghparast-Bidgoli et al. (2019)(26)

Figure 4: Composition of total program costs by UPAVAN intervention arm

NSA: Nutrition-sensitive agriculture; PLA: Participatory Learning and Action; AGRI: Nutrition-sensitive agriculture intervention; AGRI-NUT: Nutrition-sensitive and nutrition-specific agriculture intervention; AGRI-NUT+PLA: Nutrition sensitive and nutrition-specific agriculture intervention using Participatory Learning and Action approach

Tables

Table 1: Population coverage and participation in the UPAVAN interventions

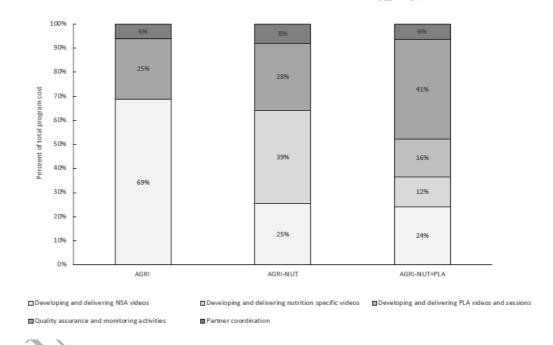|	AGRI	AGRI-NUT	AGRI-NUT+PLA	Mean
Population				
Number of clusters, n	37	37	37	
Number of pregnant women and mothers of children < 2 years in intervention clusters, n				
Total population (all ages) in intervention clusters, n	51,220	50,094	60,681	53,998
Coverage				
Primary participants[1], n	4,389	4,347	4,965	4,567
Number of women (any age) who participated, n	9,202	9,272	9,626	9,367
Participation				
Average number of participants per video dissemination **group, n (range)**	20 (14- 25)	19 (13-25)	18 (13-25)	19 (13-25)
Total group meetings attended by primary participants, n	61,446	60,858	44,685	55,663
Total home visits to primary intervention participants, n	59,482	57,051	33,052[2]	49,862
Total group meetings attended by all people, n	368,080	343,064	298,406	336,517
Total points of contact with all people [3], n	427,562	400,115	331,458	386,378

[1] Primary participants were pregnant women and mothers of children 0-23 months of age who attended at least one dissemination group meeting and received a follow-up home visit.

[2] Facilitators aimed to conduct home visits after every video dissemination group meeting but only after some Participatory Learning and Action meetings when appropriate, so fewer home visits were planned in the AGRI-NUT+PLA arm.

[3] Total points of contact is sum of total dissemination meeting attendance by all people and total home visit.

Table 2: Cost description of the UPAVAN interventions from program perspective

Description	AGRI		AGRI+NUT		AGRI+NUT+PLA	
	US$[1]	%	US$[1]	%	US$[1]	%
Total economic cost of program	272,121		366,686		386,907	
Start-up costs	71,176	26%	108,978	30%	89,905	23%
Implementation costs	200,945	74%	257,708	70%	297,002	77%
Annual total economic costs[2]	79,645		107,323		113,241	
Annual implementation costs[3]	75,354	95%	96,641	90%	111,376	98%
Economic costs of main intervention components						
Developing and delivering NSA videos	186,912	69%	93,456	25%	93,456	24%
Developing and delivering nutrition specific videos	0	0%	142,007	39%	47,336	12%
Running PLA sessions and developing nutrition specific videos through PLA	0	0%	0	0%	61,557	16%
Quality assurance and monitoring activities	69,041	25%	101,976	28%	160,139	41%
Partner coordination	16,167	6%	29,247	8%	24,419	6%
Training government frontline workers[4]	4,750	N/A	4,750	N/A	4,750	N/A

[1] 2019 US$

[2] Mean annual total intervention costs over a time horizon of 41 months.

[3] Mean annual total costs during implementation period over implementation period of 32 months

[4] These costs are not included in total program costs as they were implemented in all arms including the control arm.

Table 3: Total economic program costs from program perspective, by line item and UPAVAN intervention arm

	AGRI		AGRI-NUT		AGRI-NUT+PLA	
	US$[1]	%	US$[1]	%	2019 US$[1]	%
Staff	162,153	60%	203,805	56%	249,794	65%
Materials	2,848	1%	3,445	1%	3,159	1%
Capital	10,836	4%	16,539	5%	23,438	6%
Other recurrent	96,284	35%	142,897	39%	110,516	29%
Total	272,121		366,686		386,907	

[1] 2019 US$. An annual discount rate of 3% has been applied.

AGRI: Nutrition-sensitive agriculture intervention; AGRI-NUT: Nutrition-sensitive and nutrition-specific agriculture intervention; AGRI-NUT+PLA: Nutrition sensitive and nutrition-specific agriculture intervention using Participatory Learning and Action approach; UPAVAN: Upscaling Participatory Action and Videos for Agriculture and Nutrition

Table 4: UPAVAN interventions' costs and cost-efficiency by intervention arm

Description	AGRI	AGRI-NUT	AGRI-NUT+PLA
Program costs and program cost-efficiency (US$)[1]			
Total cost	272,121	366,686	386,907
Total cost per primary intervention participant [2]	62	84	78
Annual cost[3] per primary intervention participant	18	25	23
Total cost per point of contact[4]	0.64	0.92	1.17
Societal costs (US$)			
Total costs to the public healthcare providers	6,125	4,735	5,025
Costs of increase in use of services	7,793	1,680	5,096
Opportunity costs of involvement of frontline workers in interventions	3,527	4,174	3,326
Total opportunity costs to the participants of attending the dissemination group meetings and home visits [5]	266,228	248,814	209,433
Total societal costs and cost-efficiency (US$)			
Program + Provider costs	283,441	372,541	395,329
Societal costs (Program + Provider + Participant)	549,668	621,355	604,762
Total societal cost per primary intervention participant[2]	125	143	122
Total societal cost per points of contact	1.29	1.55	1.82

[1] 2019 US$.

[2]Primary intervention participants were pregnant women and mothers of children 0-23 months of age who attended at least one dissemination group meeting and received a follow-up home visit.

[3] Mean annual total costs over a time horizon of 41 months.

[4] Total points of contact is sum of total dissemination meeting attendance and total home visits.

[5] included costs incurred by 'primary intervention participants', and all other women who attended at least one dissemination group meeting.

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Table 5: UPAVAN interventions' consequences, measured as effects on trial outcomes among trial participants included in the endline survey

	Control	AGRI vs Control		AGRI-NUT vs Control		AGRI-NUT+PLA vs Control	
	N	*n*	aRR (95% CI)	*n*	aRR (95% CI)	*n*	aRR (95% CI)
Child minimum diet diversity (ate ≥4 food groups)	757	822	1.06 (0.91,1.23),	812	1.19 (1.03, 1.37)[1]	863	1.27 (1.11,1.46)[1]
Maternal minimum diet diversity (ate ≥5 food groups)	997	1100	1.21 (1.01,1.45)[1]	1055	1.16 (0.98,1.38)	1139	1.30 (1.10,1.53)[1]
Child minimum acceptable diet	790	862	1.01 (0.86,1.19)	829	1.19 (1.02,1.41)[1]	895	1.30 (1.12,1.52)[1]
Women made ≥ 2 decisions in agriculture or health	997	1100	1.05 (1.00,1.11)[1]	1055	1.05 (0.99,1.1)	1139	1.02 (0.96,1.07)
Total value of agricultural production over 1 year (US$)	996	1100	108 (31,231)[1]	1053	-5 (-134,118)	1138	70(-2,190)
Net value (total value minus input costs) of agriculture production over 1 year (US$)	996	1100	97 (25,219)[1]	1053	-3 (-131,112)	1138	76(12,196)

[1] Significantly different from the control arm, P < 0.05.

AGRI: Nutrition-sensitive agriculture intervention; AGRI-NUT: Nutrition-sensitive and nutrition-specific agriculture intervention; AGRI-NUT+PLA: Nutrition sensitive and nutrition-specific agriculture intervention using Participatory Learning and Action approach; aRR: adjusted relative risk, only reported for the statistically significant outcomes of the trial. UPAVAN: Upscaling Participatory Action and Videos for Agriculture and Nutrition

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Table 6: Cost-outcome results from UPAVAN interventions, by intervention arm

	AGRI	AGRI+NUT	AGRI+NUT+PLA
Total program cost (US$)	272,121	366,686	386,907
Primary intervention participants[1] covered (n)	4,389	4,347	4,965
Mean child DDS	0.0 (95% CI -0.15, 0.16)	0.13 (95%CI -0.04, 0.30)	0.28 (95%CI 0.13, 0.44)[3]
Mean maternal DDS[2]	0.12 (95%CI -0.06, 0.30)	0.14 (95%CI -0.03, 0.31)	0.24 (95% CI 0.08, 0.41)[3]
Cost per primary intervention participants (US$)	62	84	78
Cost-outcome (child DDS)	-	603	278
Cost-outcome (maternal DDS)	517	603	325

[1]Primary intervention participants (pregnant women and mothers of children under 2 years of age who attended at least one women's group meeting)

[2]One result from baseline missing due to implausible value

[3]Significantly different from the control arm, P < 0.05

DDS: Dietary diversity score; AGRI: Nutrition-sensitive agriculture intervention; AGRI-NUT: Nutrition-sensitive and nutrition-specific agriculture intervention; AGRI-NUT+PLA: Nutrition sensitive and nutrition-specific agriculture intervention using Participatory Learning and Action approach

Table 7: Results from sensitivity and scenario analyses, by UPAVAN intervention arm (all in US$[1])

Scenarios/ Parameters	Intervention arms					
	AGRI		AGRI+NUT		AGRI+NUT+PLA	
	Total costs[2]	Cost per primary intervention participant[3]	Total costs	Cost per primary intervention participant	Total costs	Cost per primary intervention participant
Base-case scenario	272,121	62	366,686	84	386,907	78
Allocation rule for nutrition specific component between arms 2 & 3 (Base-case 75% vs. 25%)						
Alternative allocation rule: 90% vs. 10%	272,121	62	403,726	93	349,867	70
Discount rate (Base-case 3%)						0
Discount rate-0%	284,880	65	382,748	88	405,884	82
Discount rate-6%	260,470	59	352,000	81	369,612	74
Start up costs (Base-case 100%)						
Reduce start-up costs by 50%	236,533	54	312,197	72	341,955	69
MIS costs (Base-case 100%)						
Reducing MIS costs by 25%	254,860	58	341,192	78	346,872	70
Reducing MIS costs by 50%	237,600	54	315,698	73	306,837	62
Replacing international costs with local staff						
International costs	182,849	42	219,025	50	294,963	59

[1] 2019 US$

[2] Program costs

[3] Primary intervention participants were pregnant women and mothers of children aged 0-23 months who attended at least one dissemination group meeting.

AGRI: Nutrition-sensitive agriculture intervention; AGRI-NUT: Nutrition-sensitive and nutrition-specific agriculture intervention; AGRI-NUT+PLA: Nutrition sensitive and nutrition-specific agriculture intervention using Participatory Learning and Action approach; MIS: monitoring information system; UPAVAN: Upscaling Participatory Action and Videos for Agriculture and Nutrition.