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Rural schools as effective hubs for agricultural technology dissemination: experimental evidence from Tanzania and Uganda

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Abstract

Increasing agricultural productivity by promoting high-yielding and micronutrient-rich crop varieties has the potential to reduce poverty and malnutrition. However, getting these technologies into the hands of smallholders remains a challenge. This paper presents results from a randomised field experiment that uses rural primary schools as dissemination hubs for improved orange-fleshed sweet potato (OFSP) vines and nutrition information in rural Tanzania and Uganda. Two years after the initial vine distribution, we find that households in treatment villages are 21 percentage points more likely to report growing OFSP and 27 percentage points more likely to correctly state the nutritional benefits of OFSP compared to those in control villages. We also find up to 16 percentage point increase in the likelihood of OFSP consumption by children under 5 years of age in treatment villages compared to that in control villages. Furthermore, we find suggestive evidence that increased knowledge on the nutritional benefits of OFSP mediated up to a third of the total treatment effect on OFSP adoption and consumption. Our findings suggest that rural primary schools can be effective channels for promoting and accelerating the diffusion of micronutrient-rich crop varieties in rural areas.

Keywords: adoption, OFSP, nutrition, school, field experiment, Tanzania, Uganda

JEL codes: C93, O12, O13, Q12, Q16

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1. Introduction

Improving agricultural productivity by promoting high-yielding and nutritious and improved crop varieties is key to reduce poverty and malnutrition (Conley and Udry, 2010; Dercon and Gollin, 2014; Diao, Hazell and Thurlow, 2010; Foster and Rosenzweig, 2010; Irz *et al.*, 2001; Ligon and Sadoulet, 2018). Yet, the adoption rate of existing nutritious and improved varieties is strikingly low in most sub-Saharan African countries (Bulte *et al.*, 2014; Conley and Udry, 2010; Duflo, Kremer and Robinson, 2008; Karlan *et al.*, 2014; Suri, 2011). A commonly cited explanation for the low adoption rates of improved agricultural technologies is information asymmetry, particularly ineffective dissemination approaches (Aker, 2011; Conley and Udry, 2010; Davis *et al.*, 2012; Di Falco *et al.*, 2018, 2019; Jack, 2011; Larsen and Lilleør, 2014; Spielman and Ma, 2016). Existing evidence (e.g. Aker, 2011; Spielman and Ma, 2016) also documented limited success from traditional extension-based technology dissemination approaches in boosting adoption. In addition, even when improved and nutritious varieties are readily available, getting them into the hands of smallholder farmers remains a challenge due to seed and input market imperfections (Bulte *et al.*, 2014; Di Falco *et al.*, 2018; Jack, 2011; Spielman and Ma, 2016; Wossen *et al.*, 2019). This is particularly the case for micronutrient-rich crop varieties such as orange-fleshed sweet potato (OFSP) for which adoption relies more on convincing farmers about its nutritional value instead of profitability (de Brauw *et al.*, 2018; Hotz *et al.*, 2012).

OFSP varieties are particularly high in vitamin A, a nutrient that supports the immune system and the development of human eyesight (World Health Organization, 2009). Steady consumption of OFSP has been shown to be an effective strategy to reduce vitamin A deficiency (VAD), especially among children in rural areas (Hotz *et al.*, 2012). However, the adoption of OFSP varieties remains low in most developing countries despite the crop being a source of vitamin A. This paper provides empirical evidence on the impact of a fast-track (FT) project, a pilot project that uses rural primary schools as dissemination channels of OFSP varieties and nutrition messages to smallholder farmers in rural Tanzania and Uganda. In these countries, most villages have access to public schools as primary school education is free. Due to their continuous and intensive contact with children and their parents, primary schools can thus be attractive hubs for diffusing nutrition information and nutritious and improved crop varieties such as OFSP (Schreinemachers *et al.*, 2017, 2019; Sharma *et al.*, 2021). As such, the FT project randomly assigned 60 primary schools in five districts of Tanzania and Uganda to treatment and control schools to test whether distributing starter packs of OFSP vines would boost the adoption and consumption of OFSP.

The core intervention package of the FT project consists of a one-time distribution of starter packs of OFSP vines to students at treatment schools. The students were then asked to take the vines back home to their parents for planting. Furthermore, to accelerate the diffusion of OFSP varieties, parents receiving vines from schools were encouraged to multiply vines and give equivalent-sized starter packs to at least two co-villagers, a process called *give-double*. The FT project also trained farmers and schoolchildren in relevant OFSP agronomy and nutrition topics. The nutrition training intervention was designed to create awareness about the benefits of OFSP, given the high rate of VAD among schoolchildren in Tanzania and Uganda. For example, about 24 per cent of pre-school aged children in Tanzania are vitamin A deficient (World Health Organization, 2009). Similarly, about 28 per cent of pre-schoolchildren in Uganda are vitamin A deficient (de Brauw *et al.*, 2018; Wirth *et al.*, 2017). Therefore, targeting children in rural primary schools is likely to be effective in improving the consumption of OFSP, an effective approach to reduce VAD among children in rural areas (de Brauw *et al.*, 2018).

In this paper, we evaluate the impact of the FT project interventions on two primary outcomes: OFSP adoption and consumption. Since our evaluation design was blind to the specific households that received the FT interventions, we estimate the intention-to-treat (ITT) effect by comparing outcomes in treatment and control villages (Burke, Bergquist and Miguel, 2019; Omotilewa *et al.*, 2018). In addition, we attempt to unpack heterogeneity impacts by comparing adoption and consumption outcomes between primary and secondary beneficiaries in treatment villages. Two years after the initial vine distribution, we find that households in treatment villages are 21 percentage points more likely to report growing OFSP and 27 percentage points more likely to correctly state the nutritional benefits of OFSP compared to those in control villages. We also find up to 16 percentage point increase in the likelihood of OFSP consumption by children under 5 years of age in treatment villages compared to those in control villages. Furthermore, our causal mediation analysis suggests that increased knowledge on the nutritional benefits of OFSP mediated up to a third of the total treatment effect on OFSP adoption and consumption. Finally, we also find significant adoption and consumption impacts for secondary beneficiaries in treatment villages, suggesting that the vines introduced through the school system were further disseminated within treatment villages. Overall, our results suggest that rural primary schools can play a critical role in bolstering extension service capacities in rural areas around certain types of agricultural technologies. By relying on an already established mode of engaging rural households, schools can potentially be a cost-effective channel for pushing technologies out and reaching farmers in remote rural areas. Furthermore, the evidence from this paper suggests that interventions that promote food-based solutions to addressing micronutrient deficiencies can rely on pupils for messaging to boost cultivation and consumption of micronutrient-rich food crops. Beyond the narrow objective of addressing VAD, schools can also be a viable alternative for improving seed systems, especially for vegetatively propagated crops.

The remainder of the paper is organised as follows: Section 2 presents an overview of extension-based approaches for promoting agricultural technologies to smallholders. Section 3 presents the context of our study, the experimental design, data and summary statistics. Section 4 presents our estimation results and Section 5 provides concluding remarks.

2. Traditional technology dissemination approaches

Much of the literature that attempts to address the question of how to get new technologies to the farms of smallholder farmers tackle it from the agriculture extension services point of view (Abebaw and Haile, 2013; Anderson and Feder, 2004, 2007; Davis *et al*., 2012; Wossen *et al*., 2017). Public extension systems are charged with linking research and development (R&D) outputs to the farms of farmers in much of Africa, south of the Sahara. This may include providing information about new technologies, exposing farmers to trial plots and sharing new technologies with farmers for them to try out and evaluate performance. Where public extension systems exist, they have worked with varying degrees of success at boosting adoption rates of new technologies across the developing world (Anderson and Feder, 2007; Bernard and Spielman, 2009; Verhofstadt and Maertens, 2015). Unfortunately, in most parts of Africa, south of the Sahara, public extension systems are either non-existent or grossly under-supplied. For instance, the 2018 Africa Agriculture Status Report (AGRA, 2018) states that the ratio of extension agents per farmers across the continent ranges from three to twenty-one agents per 10,000 farmers.

Furthermore, underdeveloped transport links, low literacy rates and limited connections to electronic mass media make reaching farmers in remote locations challenging. The scale, complexity and the associated cost of reaching farmers are insurmountable for most public extension systems. In Uganda, for instance, several reform efforts of the extension system have left it crippled and non-functional (Barungi, Guloba and Adong, 2015). In Tanzania, there is about one public extension worker per village, but the average village in the project areas has several thousand farmers, this makes it difficult to introduce new technologies through this channel. Consequently, the public extension systems across the continent have not been able to adequately deliver new technologies to smallholders (Anderson and Feder, 2007).

Alternative models of providing extension services exist with various advantages and drawbacks. Group-centred models such as producers or farmer groups, credit groups or other social groups rely on informal network connections to spread new agricultural technologies (Bernard and Spielman, 2009; Di Falco *et al*., 2018; Shiferaw, Hellin and Muricho, 2011). Several studies (e.g. Abebaw and Haile, 2013; Bernard and Spielman, 2009; Shiferaw, Hellin and Muricho, 2011) highlighted the limitations of group-based approaches in disseminating improved technologies to the most disadvantaged and marginal farmers. Private sector models such as agro-dealers and input sellers also lack the required incentive structures to promote some beneficial technologies such as OFSP due to the unique biological characteristics of such technologies (Shiferaw, Obare and Muricho, 2008; Spielman and Ma, 2016). For example, farmers can capture the economic benefits of improved genetic quality without having to remunerate the inventors due to the possibility of recycling planting materials (Wossen *et al.*, 2019, 2020).

3. Context, sampling and experimental design

3.1. Description of the FT interventions

The goal of the FT project was to evaluate the impact of an innovative model of diffusing nutritious and improved varieties of vegetatively propagated crops, with a focus on sweet potato. The FT project took place in 10 districts in Tanzania and three districts in Uganda. The impact evaluation took place in Wakiso and Mukono districts in Uganda and Bukoba, Missenyi and Mkuranga districts in Tanzania. The FT project was piloted in two phases. The first phase is a start-small approach focusing on a few specific locations in the nonimpact evaluation areas in early 2015 to allow both implementers and the evaluation team to learn and standardise project activities. The second phase was a complete rollout of the standardised package of interventions in all project districts. The monitoring and evaluation team used the 'start-small' phase to conduct baseline data collection in the impact evaluation districts from November 2015 to February 2016. We found that although adoption rates of improved varieties were relatively higher (ranging from an average of 35 per cent in Tanzania to about 60 per cent in Uganda), OFSP varieties were much less adopted. A strong focus was then given to the distribution of OFSP vines.

The core intervention packages of the FT project include the distribution of starter packs of approximately 120 sweet potato vines cuttings, of which at least half are OFSP, to students in public primary schools in Tanzania and Uganda.[1] In all project locations, at least two different varieties of OFSP and in some cases four different varieties were distributed. The number of vine cuttings given to students was deliberately small, with the idea being that if farmers try the varieties and like them, they can invest time and resources to conserve them or buy them in the market for future planting. At the end of one planting season, the parents of students that received vines from the project were asked to *give-double* by preserving the vines generated by their starter packs and providing starter packs of equivalent size and quality to two other co-villagers.[2] The *give-double* vine exchange is expected to reduce vine dissemination costs and accelerate OFSP uptake by facilitating within village diffusion to secondary beneficiaries (Di Falco *et al.*, 2019). Vine diffusion could also take place outside of the formal *give-double* exchanges, which may further increase the number of households reached by the initial school-based distribution. Vine distribution was accompanied by the following additional

1 Analysis of project administrative data shows that approximately 65 and 60 per cent of the vines distributed in impact evaluation schools in Tanzania and Uganda were OFSP, with remainder being other improved sweet potato varieties.

2 In practice, *give-double* took place at a variety of different time across the 2-year project period depending on local rainfall. Further, the requirement to give 120 vines to each recipient farmer was relaxed due to farmers only being able to maintain a relatively small number of vines through exceptionally long dry seasons during the project.

activities aimed at generating demand and improving cultivation practices: (i) training sessions on OFSP nutritional benefits: the FT held dedicated nutrition information sessions by a sweet potato nutrition expert with pupils at schools about the nutritional benefits and potential uses of OFSP. In some cases, farmers were invited to nutrition training sessions at schools; (ii) demonstration plots: small plots of improved sweet potato were established at project schools and, in some cases, village centres. School plots provided food for pupils, which allowed them to taste OFSP. Pupils also got to eat OFSP they cultivated in their school gardens and (iii) farmer field days: events organised by the project implementation team promoted sweet potato cultivation and marketing for farmers in project villages. In some cases, these events were also used to encourage secondary vine distribution through *give-double*.

3.2. Sampling and evaluation design

The goal of the evaluation was to test whether distributing starter packs of OFSP varieties and associated agronomic and nutrition information through primary schools would boost adoption and consumption levels of OFSP. Hence, we designed a two-arm clustered randomised controlled trial (RCT) focused on measuring village level OFSP adoption and consumption outcomes. To this end, 60 schools in the evaluation areas were randomly assigned to either treatment or control groups.[3] In total, the evaluation consisted of 40 treatment schools that received all the components of the FT intervention and 20 control schools that served as a counterfactual.[4] We linked each school to the village where it is located to create a list of treatment and control villages. Hence, although the unit of randomisation was the school, the unit of analysis was the village primarily associated with the school and only one school was selected per administrative Ward (in Tanzania) or Parish (in Uganda), which also helped minimise spillover between treatment and control villages.[5]

Once schools were selected, a total of 20 households from each village in which the school is located were randomly selected from two sampling frames to participate in the survey.[6] First, eight students were randomly selected from a school register of students enrolled at the primary school. Once a student is selected, they are linked to their parent or guardian households in the village. Two students from the same household could not be selected from the school

3 Note that these schools were randomly selected from a list of feasible schools. Feasibility was defined as having more than 250 students on the roster, sweet potato cultivation in the area, the surrounding village being solely served by the school and 50 per cent of the students in the school from the surrounding village. The research team made all school eligibility decisions based on school rosters and conversations with the school administration.

4 Randomisation was stratified on the proportion of households growing OFSP in Uganda and Kagera and on the portion of households growing sweet potato in the past year in Mkuranga where no households grew OFSP at baseline.

5 The administrative units in Uganda are District, Subcounty, Parish and Village; in Tanzania the units are District, Ward and Village.

6 The sample size of the evaluation was determined based on power calculations for primary outcomes (uptake and consumption of OFSP). The primary and secondary outcomes were registered in a pre-analysis plan and submitted to the Registry for International Development Impact Evaluations with study ID 58261c9858e44.

list, and any student whose household was located in a different village was replaced. Second, 12 households were randomly selected from a list of farming households who were likely targets for the programme. This list of village households was obtained through local extension agents and contained households who currently grow sweet potato or might be interested in growing sweet potato in the future. If the same household was selected via village sampling and student sampling, no replacements were made. However, replacements were made if the initially selected farmers were unable to respond or were not sweet potato farmers.

This sampling procedure would allow us to distinguish programme effects on primary recipients (who received vines through schools) as well as secondary beneficiary households in the treatment villages (who primarily received vines through *give-double* activities and to a lesser extent directly from schools). That is, households in the treatment school sample are more likely to be direct beneficiaries of the intervention. Their children are expected to bring vines home and share nutrition information at home. Hence, in addition to comparing outcomes between treatment and control villages, we also compare outcomes across the three comparison groups: treatment school sample, treatment village sample and control sample. This comparison allows us to understand whether the project impact spread beyond households associated with schools. However, since our evaluation design did not vary the intensity of project interventions across treatment schools (i.e. the treatment schools received the full intervention package, while the control villages received none), it will be almost impossible to conclusively determine which elements of the FT intervention packages are the most important in driving impact.

3.3. Study timeline and outcome measures

The evaluation consisted of a baseline data collection in November 2015–February 2016 and an endline data collection from the same households in June and July 2018. Initial vine distribution took place in March and April 2016 in the treatment schools with *give-double* activities continuing into 2017. This period covered three to four complete planting seasons. The endline survey was conducted following the same structure as the baseline survey. The survey dedicated detailed modules to collect data on our two main outcomes: adoption and consumption of OFSP. To measure OFSP adoption, we relied primarily on farmers' recall of growing OFSP varieties. In particular, we measured OFSP adoption both at the intensive and extensive margins. At the extensive margin, we used an indicator variable that takes a value of 1 if the household reports growing an OFSP variety or 0 otherwise. As a robustness check, we also measured OFSP adoption based on the names of sweet potato varieties farmers provided to enumerators. At the intensive margin, OFSP adoption was measured using the fraction of OFSP vines from total sweet potato cuttings and the proportion of OFSP area from the total sweet potato area.[7]

7 This is conditional on the farmer growing sweet potato.

Next, since both households and pupils were trained about the nutritional benefits and potential uses of sweet potato, the survey also collected detailed information to measure households' knowledge about the nutritional benefits of OFSP. In particular, we asked respondents to name the nutritional benefits of OFSP and some recipes of OFSP. In our analysis, we measured nutrition knowledge both at the extensive (i.e. by an indicator variable that takes a value of 1 if the household knows at least one benefit/recipe promoted by the FT project or 0 otherwise) and intensive (i.e. based on the number of benefits/recipes the household knows) margins.[8] To measure OFSP consumption, we collected detailed information about diets consumed in the households using a 24-hour and 7-day recall period. In our main analysis, OFSP consumption is measured by an indicator variable that takes a value of 1 if a household member reports consuming OFSP based on the 24-hour or 7-day recall period or 0 otherwise. We also evaluated impacts on consumption of OFSP by children under 5 years of age. In this case, OFSP consumption was measured by an indicator variable that takes a value of 1 if a household had a child that consumed OFSP or 0 otherwise.[9]

3.3.1. Baseline randomisation balance checks

The baseline study sample consisted of 1,196 households in 60 villages. Table 1 presents the summary statistics for pre-treatment characteristics of survey participants at baseline. Table 1 shows that at baseline, treatment and control groups were similar in almost all key characteristics that may determine OFSP adoption and consumption outcomes.

However, randomisation did not achieve balance for the adoption of non-OFSP improved sweet potato varieties, with a higher adoption rate among households in control villages compared to those in treatment villages. Randomisation also did not achieve balance with respect to plot size and the total number of vine cuttings cultivated.[10] Furthermore, Table A15 (Appendix in supplementary data at ERAE online) reported in the Appendix shows that at baseline, the treatment school, treatment village and control groups were similar in most characteristics, except in age, plot size and adoption of non-OFSP improved sweet potato varieties.

3.3.2. Attrition

In the endline survey, we attempted to interview exactly the same number of households interviewed at baseline. However, we were able to visit 1,064 out of the 1,196 households interviewed at baseline, resulting in an attrition rate of 11 per cent. There were a variety of reasons for attrition. In some areas, there were high rates of out-migration to nearby urban centres such as

8 Among others, knowledge on the nutritional benefits of OFSP includes listing the following nutritional benefits of OFSP: source of vitamin A, strengthens immune system, source of minerals, helps the eyes, good for children and pregnant women.

9 This is conditional on the household having a child. In our case, about 38 per cent of the respondents have at least one child under 5 years of age.

10 In our empirical estimation strategy, we control for such baseline imbalances.

Table 1. Baseline characteristics and balance between treatment and control groups

Variable	(1) Control Mean (SE)	(2) Treatment Mean (SE)	(3) Total Mean (SE)	*t*-Test Difference (1) – (2)
Age	43.7 (0.74)	45.1 (0.56)	44.63 (0.45)	−1.41
Sex (1 = female)	0.373 (0.024)	0.358 (0.017)	0.363 (0.014)	0.016
Education (1 = illiterate)	0.130 (0.017)	0.133 (0.012)	0.132 (0.010)	−0.003
Plot size (acres)	0.306 (0.027)	0.235 (0.017)	0.259 (0.015)	0.071**
Received sweet potato training	0.048 (0.011)	0.043 (0.007)	0.044 (0.006)	0.005
Fraction of OFSP vines	0.010 (0.004)	0.013 (0.003)	0.012 (0.002)	−0.003
Fraction of other improved vines	0.184 (0.017)	0.169 (0.012)	0.174 (0.010)	0.014
Total vine cuttings (*n*)	1,232.7 (252.4)	1,924.43 (247.6)	1,693.7 (185.4)	−692*
Ever received sweet potato vines	0.123 (0.016)	0.123 (0.012)	0.123 (0.009)	−0.000
Aware of OFSP varieties (1 = yes)	0.589 (0.025)	0.605 (0.017)	0.599 (0.014)	−0.016
Nutrition knowledge (1 = yes)	0.211 (0.020)	0.21 (0.014)	0.21 (0.012)	0.001
Consumption of OFSP by children (1 = yes)	0.065 (0.012)	0.055 (0.008)	0.059 (0.007)	0.010
Planted OFSP varieties	0.048 (0.011)	0.045 (0.007)	0.046 (0.006)	0.002
Planted other improved varieties	0.308 (0.023)	0.258 (0.016)	0.275 (0.013)	0.05*
n	399	797	1,196	

Notes: The values displayed for *t*-tests are the differences in the means across the groups. ** and * indicate significance at the 5 and 10 per cent critical levels, respectively.

Dar es Salaam, Bukoba and Kampala. The survey was relatively long, and a substantial number of respondents did not consent to the survey (2 per cent). Additionally, some respondents could not be traced despite using local leaders to locate them. This may have been due to respondents at baseline providing nick names that are not known by local leaders in the village. While the relatively large attrition rate was balanced across arms ($p = 0.88$), we checked whether attrition was random to rule out selective attrition. To do so, we ran a probit model where baseline characteristics along with their interactions with treatment status were included as predictors of attrition (i.e. attrition takes a value of 0 if the household was interviewed in both baseline and endline surveys or 1 otherwise). The correlates of attrition reported in Table A14 (Appendix in supplementary data at ERAE online) in the Appendix shows the absence of attrition bias in our sample.[11] Hence, our evaluation is based on the 1,064 households that were interviewed both at baseline and endline.

3.4. Estimation

In this section, we present the empirical strategy employed to estimate the impact of FT interventions on OFSP adoption and consumption outcomes. While the same households were interviewed during each survey round, the treatment effects are estimated by comparing outcomes between households in treatment and control villages rather than analysing the change in outcomes of households over time.[12] In addition, due to its policy relevance and given that our sampling design for evaluation was blind to the specific households that received FT interventions, we estimate the ITT effect instead of the local average treatment effect (LATE) (Omotilewa *et al.*, 2018).[13] Let Y_{ij} be the outcome variable of interest for household i in village j (OFSP adoption, OFSP nutrition knowledge and OFSP consumption). Let T_{ij} be an indicator for whether household i in village j was assigned to treatment/control group. Following our pre-analysis plan, we employ analysis of covariance (ANCOVA) as our preferred empirical specification. By controlling for baseline values of outcome variables, the ANCOVA specification utilises the baseline data better than a simple comparison of post-intervention means (McKenzie, 2012). Thus, we employ the following specification to estimate the ITT effect:

$$Y_{ij} = \alpha + \beta_{itt} T_{ij} + \gamma Y_{i0} + \zeta X_{i0} + v_s + \varepsilon_{ij} \quad (1)$$

where X_{i0} is a vector of baseline household characteristics included for precision, Y_{i0} is a vector of baseline outcomes and v_s stands for strata dummies. β_{itt} is our parameter of interest and is an estimate of the impact of the FT project interventions (i.e. vine distribution and exposure to FT nutrition and agronomic trainings) on OFSP adoption/consumption outcomes.

Next, since our sampling design for evaluation was blind to the specific households that received FT interventions, we also estimated impacts on primary and secondary beneficiary households. That is, because schools were the

11 Evidence of such differential selection on observables exists if some of the interactions are significant predictors of attrition. Under this scenario, the appropriate approach would be weighting observations by the inverse of their probability of being retained at endline in a spirit of selection on observables assumption.

12 As noted above, there are a large number of sweet potato projects in FT districts and thus increases in uptake over time alone cannot be definitively attributed to FT alone.

13 As a robustness check, we also report LATE estimates for our main outcomes in Section (4.8).

main focus of project activities, a possible concern would be that households not associated with schools (i.e. because they don't have children in school) would not experience the benefits of the project. As such, we examine the presence of possible heterogeneity impacts by comparing outcomes between primary and secondary vine recipient households in treatment villages. As discussed before, a primary recipient refers to a household that received vines directly from the school-based distribution events. The households sampled from school enrolment lists were supposed to receive vines directly. On the other hand, secondary recipients refer to households that are less likely to directly receive vines from the school, perhaps because they are less likely to have a child attending school. However, these households are more likely to obtain vines from primary recipients through *give-double* exchanges and to a lesser extent from schools directly through their children (i.e. these are households sampled from the village list in treatment villages). Hence, the presence of heterogeneous impact is examined using the following regression specification:

$$Y_{ij} = \alpha + \varphi S_{ij} + \psi V_{ij} + \gamma Y_{i0} + \zeta X_{i0} + v_s + \epsilon_{ij} \quad (2)$$

where S_{ij} is an indicator variable that takes a value of 1 for households in treatment villages selected from the school list and 0 for control villages. Similarly, V_{ij} is an indicator variable that takes a value of 1 for households in treatment villages selected from the village list and 0 for control villages. Hence, a test of the significance of $\varphi - \psi > 0$ is a test of the presence of heterogeneous treatment effect in the sense that the impact of FT project on primary and secondary beneficiary households is not the same.[14]

4. Results

In this section, we first report the ITT estimates on OFSP adoption, nutrition knowledge and consumption outcomes. We then introduce a causal mediation analysis framework to quantify the contribution of nutrition knowledge to OFSP adoption and consumption. In what follows, we undertake several robustness checks to verify the sensitivity of our main impact estimates. Finally, we also report cost-effectiveness estimates to put our impact estimates into perspective.

4.1. Uptake of OFSP

Table 2 reports the estimated treatment effects focusing on OFSP adoption at the extensive margin.[15] The outcome variable in Table 2 is an indicator variable that takes a value of 1 if the household is growing OFSP at the endline or 0 otherwise. As discussed before, we measured OFSP adoption using two approaches: farmers' recall of growing OFSP varieties that takes a value of

14 Note that this comparison also assumes that the sampling source (i.e. whether the household was selected from the school or village list) is independent of potential outcomes.

15 For comparison, the LATE estimates are reported in Section (4.8).

Table 2. Impact on of OFSP adoption

	Farmer recall				Variety names			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment	0.208***	0.207***	0.214***		0.195***	0.196***	0.199***	
	(0.043)	(0.043)	(0.037)		(0.04)	(0.04)	(0.037)	
Treatment village sample: ψ				0.166***				0.144***
				(0.042)				(0.043)
Treatment school sample: φ				0.280***				0.274***
				(0.042)				(0.042)
$\varphi - \psi$				0.114***				0.130***
				(0.04)				(0.042)
Endline control mean	0.245	0.245	0.245	0.245	0.232	0.232	0.232	0.232
Baseline covariates	No	No	Yes	Yes	No	No	Yes	Yes
Baseline outcome	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064	1,064	1,064

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical level, respectively. Treatment school sample is an indicator variable that takes a value of 1 if the household in treatment villages is selected from the school list and 0 for control villages. Treatment village sample is also an indicator variable that takes a value of 1 if the household in treatment villages is selected from the village list and 0 for control villages. All regressions include strata dummies. Baseline outcome is an indicator variable that takes a value of 1 if the household was growing OFSP at baseline or 0 otherwise. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

1 if the farmer reports growing OFSP varieties at the endline or 0 otherwise and based on the names of sweet potato varieties reported by farmers at the endline. In this case, OFSP adoption takes a value of 1 if the name of the variety that the farmer reported is an OFSP variety or 0 otherwise. In column (1), the regression includes an indicator variable for the treatment assignment, which takes a value of 1 if the household is in the treatment village and 0 if the household is in the control village. We then include baseline outcomes as additional controls in our ANCOVA regression in column (2). In column (3), we include additional baseline covariates in addition to baseline outcome measures. In column (4), we report impact estimates for the school and village samples separately.

Based on farmers' recall of growing OFSP varieties, we find that the average household in treatment villages is about 21 percentage points more likely to report growing OFSP varieties compared to those in control villages. When additional baseline outcome indicators and covariates are included as additional controls in columns (2–3), the estimated impacts remain almost the same. Column (4) shows about 28 and 17 percentage point increase in the likelihood of growing OFSP for the school and village samples in treatment villages, respectively, compared to those in control villages. Based on variety names by which OFSP is known, we also find about 20 percentage point increase in the likelihood of growing OFSP in treatment villages compared to control villages.[16] At the bottom of Table 2, we report parameter equality test ($\varphi - \psi$). It tests whether impacts on primary and secondary recipients in treatment villages (i.e. those selected from the school and village lists, respectively) are different. Our parameter equality test detects statistically significant differences, suggesting the presence of heterogeneous treatment effect in the sense that the impact of FT project interventions on primary and secondary recipients is not the same. Overall, our results suggest that the vines introduced through the school system were further disseminated, reaching households in treatment villages that the FT project had not initially targeted.

4.2. Intensity of OFSP adoption

In this section, we report impacts on OFSP adoption at the intensive margin focusing on the proportion of sweet potato area allocated to OFSP production and the fraction of OFSP vine cuttings from the total sweet potato vine cuttings. Results are reported in Table 3. Estimates reported in the first three columns show about 8 percentage point increase in the fraction of OFSP vines from the total sweet potato vine cuttings in treatment villages compared to that in control villages.[17] We also find comparable impacts based on the sweet

16 When restricting our definition of OFSP uptake to those households in which roots were observed by enumerators, there is a treatment effect of 12–18 percentage points. This is re-assuring given recent evidence showing the presence of significant crop variety misclassification/misperception (Wossen *et al.*, 2019).

17 We also find comparable impacts based on the actual number of OFSP vines planted. Households in treatment villages plant about 243 more OFSP vines compared to those in control villages. To put this into perspective, the FT project distributed about 120 vines cuttings per

Table 3. Impact on the intensity of OFSP adoption

	Fraction of OFSP vines				Share of OFSP area			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment	0.082***	0.082***	0.083***		0.077***	0.077***	0.075***	
	(0.031)	(0.031)	(0.028)		(0.027)	(0.027)	(0.023)	
Treatment village sample: ψ				0.06**				0.041
				(0.029)				(0.027)
Treatment school sample: φ				0.113***				0.119***
				(0.032)				(0.029)
$\varphi - \psi$				0.052**				0.078**
				(0.024)				(0.030)
Endline control mean	0.113	0.113	0.113	0.113	0.055	0.118	0.118	0.118
Baseline covariates	No	No	Yes	Yes	No	No	Yes	Yes
Baseline outcome	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Number of observations	878	878	878	878	850	850	850	850

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical levels, respectively. Note that the proportions, in terms of OFSP vines and area, are of farmers currently growing sweet potato. The first outcome, fraction of OFSP vines, has 88 missing observations because these households did not report the number of OFSP vines. In addition, the outcome, share of OFSP area, has 28 additional missing observations because these households did not report area under OFSP/sweet potato. Treatment school sample is an indicator variable that takes a value of 1 if the household in treatment villages is selected from the school list and 0 for control villages. Treatment village sample is also an indicator variable that takes a value of 1 if the household in treatment villages is selected from the village list and 0 for control villages. All regressions include strata dummies. Baseline outcome is the fraction of OFSP vines and OFSP adoption rate at baseline. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

potato area under OFSP cultivation. In particular, our estimates suggest about 7 percentage point increase in the share of sweet potato area allocated to OFSP cultivation in treatment villages compared to control villages.

As before, we also report impacts on both direct and indirect beneficiaries by decomposing the treatment sample into school and village samples. For both outcomes, we again find positive and significant treatment effects, particularly in the treatment school sample relative to control villages. For instance, we find about 11 and 6 percentage point increase in the fraction of OFSP vines in the treatment school and village samples, respectively, compared to that in the control group. The parameter equality test ($\varphi - \psi$) reported at the bottom of Table 3 also confirms the presence of statistically significant difference in the fraction of OFSP vines between the school and village samples in treatment villages. Similarly, we find about 12 percentage point increase in the portion of sweet potato area allocated to OFSP production in the treatment school sample relative to the control group but the difference between the treatment village sample and control villages is insignificant. This might be due to primary recipients' preference to use a large proportion of their vines to intensify their own OFSP production instead of sharing it with other co-villagers as part of the *give-double* vine exchanges. Similar findings were reported for Tanzania by Di Falco *et al.* (2018). In particular, Di Falco *et al.* (2018) documented that individuals that received improved seed reduced interaction with their social networks by sharing information on the type of seed they received with fewer people in the village.

4.3. Adoption of non-OFSP improved sweet potato varieties

In Table 4, we report impacts focusing on the adoption of non-OFSP improved sweet potato varieties. The dependent variable in our regression is an indicator variable that takes a value of 1 if the household reports growing non-OFSP improved sweet potato varieties at endline or 0 otherwise. Results reported in Table 4 suggest insignificant impacts across all specifications between treatment and control villages. As noted above, the baseline data show that a significant proportion of households were already exposed to non-OFSP improved sweet potato varieties as adoption rate was quite high both in the treatment and control villages. The null effect of our interventions might also be due to farmers' preference for OFSP varieties relative to non-OFSP varieties. From the decomposition analysis no significant difference was found between the school and village samples.

4.4. Impact on nutrition knowledge and consumption

In this section, we report impacts on our second key outcome indicator: consumption of OFSP. Before presenting impacts on OFSP consumption, we first

household, half of which being of an OFSP variety type (60 vine cuttings), implying that households in treatment villages have multiplied the initial vines they received about four times in 2 years.

Table 4. Impact on adoption of non-OFSP improved sweet potato varieties

	(1)	(2)	(3)	(4)
Treatment	0.024	0.026	0.035	
	(0.04)	(0.04)	(0.039)	
Treatment village sample: ψ				0.029
				(0.041)
Treatment school sample: φ				0.044
				(0.043)
$\varphi - \psi$				0.015
				(0.032)
Endline control mean	0.636	0.636	0.636	0.636
Baseline covariates	No	No	Yes	Yes
Baseline outcome	No	Yes	Yes	Yes
Number of observations	1,064	1,064	1,064	1,064

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical level, respectively. Treatment school sample is an indicator variable that takes a value of 1 if the household in treatment villages is selected from the school list or 0 for control villages. Treatment village sample is also an indicator variable that takes a value of 1 if the household in treatment villages is selected from the village list or 0 for control villages. All regressions include strata dummy. Baseline outcome controls include an indicator variable that takes a value of 1 if the household was growing improved non-OFSP sweet potato varieties at baseline or 0 otherwise. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

examine whether the nutrition training intervention was successful in increasing farmers' knowledge about the nutritional benefits of OFSP. We measured households' knowledge on the nutritional benefits of OFSP both at the extensive margin (i.e. by an indicator variable that takes a value of 1 if the household mentions at least one benefit of OFSP or 0, otherwise) and intensive margins (based on the number of nutritional benefits the household knows). Results are reported in Table 5.

Across all specifications, we consistently find that households in treatment villages have a much better knowledge on the nutritional benefits of OFSP, both at the intensive and extensive margins, compared to those in control villages. For instance, we find that farmers in treatment villages are 27 percentage points more likely than control village farmers to correctly state the nutritional benefits of OFSP and 14 percentage points more likely to know an OFSP recipe promoted by the FT project. These results are consistent with the findings of several other studies that leveraged school-based interventions to improve children's nutrition knowledge, attitude and practice (Benkowitz,

Table 5. Impact on knowledge about the nutritional benefits of OFSP

	Panel A: Impact at the extensive margin							
	OFSP benefits				OFSP recipes			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment	0.263***	0.262***	0.269***		0.131***	0.130***	0.136***	
	(0.044)	(0.037)	(0.033)		(0.041)	(0.041)	(0.031)	
Treatment village sample: ψ				0.232***				0.103***
				(0.037)				(0.032)
Treatment school sample: φ				0.321***				0.182***
				(0.037)				(0.036)
$\varphi - \psi$				0.089**				0.079***
				(0.037)				(0.029)
	Panel A: Impact at the intensive margin							
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment	0.591***	0.591***	0.618***		0.342***	0.342***	0.359***	
	(0.116)	(0.104)	(0.091)		(0.115)	(0.115)	(0.092)	

(continued)

Table 5. (Continued)

	Panel A: Impact at the extensive margin							
	OFSP benefits				OFSP recipes			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment village sample: ψ				0.533***				0.254***
				(0.099)				(0.093)
Treatment school sample: φ				0.734***				0.503***
				(0.10)				(0.109)
$\varphi - \psi$				0.201**				0.249***
				(0.081)				(0.085)
Baseline covariates	No	No	Yes	Yes	No	No	Yes	Yes
Baseline outcome	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064	1,064	1,064

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical levels, respectively. Treatment school sample is an indicator variable that takes a value of 1 if the household in treatment villages is selected from the school list or 0 for control villages. Treatment village sample is also an indicator variable that takes a value of 1 if the household in treatment villages is selected from the village list or 0 for control villages. All regressions include strata dummies. Baseline outcome controls include an indicator variable that takes a value of 1 if the household knows the nutritional benefits/recipe of OFSP at baseline or 0 otherwise. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

Schulz and Lindemann-Matthies, 2019; Bird *et al.*, 2019; Schreinemachers *et al.*, 2020, 2017, 2019; Sharma *et al.*, 2021). For Schreinemachers *et al.* (2017, (2019) find that a comprehensive school garden programme, combining vegetable gardening with education in agriculture in Nepal and Burkina Faso, led to significant improvement in children's knowledge of nutrition. Having established significant improvements on the nutritional benefits of OFSP varieties among households in treatment villages relative to control villages, we next report impacts on OFSP consumption by household members in general and children under 5 years of age in particular. Results reported in Table 6 suggest the FT interventions led to a 16 percentage point increase in the likelihood of OFSP consumption by households and a 17 percentage point increase in the likelihood of OFSP consumption by children under 5 years of age. This result is expected since the school-based nutrition training activities of the FT project emphasised nutrition and OFSP consumption and exposed both children and their parents to these messages. This result is consistent with the findings by Schreinemachers *et al.* (2020) that show exposing both children and caregivers to nutrition information improves both nutrition knowledge and consumption outcomes.

4.5. Causal mediation analysis

As discussed in Section 3, our evaluation design did not vary the intensity of project interventions across treatment schools/villages. The treatment villages received the full intervention package, while the control villages received none. This makes it harder to conclusively determine which elements of the intervention package were driving the observed treatment effect on OFSP adoption and consumption. As mentioned before, while the main component of the FT intervention is direct vine distribution to pupils at treatment schools, dedicated information sessions on the nutritional benefits of OFSP and improved agronomic practices constitute the complementary component of the FT intervention. However, our main estimation strategy explicated in Section (3.4) does not allow us to unpack the relative contribution of the different components that compose the full FT interventions. In their systematic review, Sharma *et al.* (2021) and Bird *et al.* (2019) suggest that nutrition-sensitive agriculture interventions could improve food production and nutritional outcomes through food production, nutrition-related knowledge, agricultural income and women's empowerment-related pathways. This is particularly important in our setting since the different components of the full FT interventions are not mutually exclusive and are expected to affect farmer's OFSP adoption and consumption decisions in several pathways. For instance, the nutrition training component of the FT project is expected to play an important role in convincing farmers to adopt OFSP or target young children as consumers of OFSP within the household (de Brauw *et al.*, 2018). Moreover, it may also affect OFSP consumption directly without influencing participant's OFSP adoption decision through market mechanisms (i.e. OFSP consumption through market purchases instead of from own production). However, quantifying/unpacking

Table 6. Impact on OFSP consumption

	OFSP consumption of household members				OFSP consumption of children			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Treatment	0.153***	0.159***	0.163***		0.174***	0.171***	0.171***	
	(0.043)	(0.042)	(0.034)		(0.043)	(0.04)	(0.035)	
Treatment village sample: ψ				0.142***				0.127***
				(0.037)				(0.04)
Treatment school sample: φ				0.190***				0.234***
				(0.042)				(0.047)
$\varphi - \psi$				0.048				0.108**
				(0.039)				(0.052)
Baseline covariates	No	No	Yes	Yes	No	No	Yes	Yes
Baseline outcome	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Number of observations	1,064	1,064	1,064	1,064	588	588	588	588

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical levels, respectively. Treatment school sample is an indicator variable that takes a value of 1 if the household in treatment villages is selected from the school list or 0 for control villages. Treatment village sample is also an indicator variable that takes a value of 1 if the household in treatment villages is selected from the village list or 0 for control villages. All regressions include strata dummies. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

how much of the treatment effect on OFSP adoption and consumption operated through additional nutrition knowledge is difficult since the FT project did not vary the intensity of nutrition training sessions among households in treatment villages.

Hence, we conduct a causal mediation analysis to identify the indirect effect (IE), which operates through improved nutrition knowledge. That is, we attempt to decompose the impacts reported in Table 2 for adoption and in Table 6 for consumption into: the direct effect (DE) and the IE that operates through mediators (i.e. improved OFSP nutrition knowledge in our case). Following Hicks and Tingley (2011); Imai *et al.* (2011) and Dippel, Ferrara and Heblich (2020), let $M(t)$ denote the potential value of the mediator under treatment status $T = t$. Similarly, let $Y(t, m)$ be the potential outcome (i.e. OFSP adoption and consumption in our case) if the treatment and mediating indicators assume t and m, respectively. The total effect (TE) (i.e. $E[Y(t_1) - Y(t_0)]$) can then be decomposed into DE and IE in the following manner:

$$\begin{aligned} DE(t) &= E\left[Y(t_1, M(t)) - Y(t_0, M(t))\right] \\ IE(t) &= E\left[Y(t, M(t_1)) - Y(t, M(t_0))\right] \end{aligned} \quad (3)$$

where $t = 0;1$ indicating treatment status. Equation (3) shows that fixing $T = t$, the IE measures the expected change in Y when the value of the mediator changes from $M(t_0)$ to $M(t_1)$, while the DE is simply the share of the TE that does not operate through M. That is, fixing $T = t$, $IE(t)$ measures the change in Y corresponding to a change in the mediator from the value that would be realised under the counterfactual condition, $M(t_0)$, to the value that would be observed under the treatment condition, $M(t_1)$ (Dippel, Ferrara and Heblich, 2020; Hicks and Tingley, 2011; Imai *et al.*, 2011). Thus, the IE will be zero when the treatment has no effect on the mediator so that $E[M(t_1) - M(t_0)] = 0$. However, identification and estimation of IE require two sequential ignorability (SI) assumptions (Imai *et al.*, 2011). The first SI assumption is treatment exogeneity, which is expected to hold in our setting since treatment status is randomised. The second SI assumption is related to mediator exogeneity and is explicated by Assumption (4.1) below.

Assumption 4.1 (Mediator exogeneity). $(Y(t,m) \perp M(t) | T = t; X = x)$

Assumption (4.1) implies that conditional on the actual treatment status and pre-treatment confounders, the observed mediator is statistically independent of potential outcomes. In our setting, this assumption implies that given treatment status and pre-treatment confounders, knowledge of nutritional benefits would be statistically independent of OFSP adoption and consumption outcomes. Even though we demonstrate that baseline OFSP nutrition knowledge was balanced through randomisation between treatment and control groups (see, Table 1), Assumption (4.1) is clearly a strong assumption since OFSP nutrition knowledge is a post-treatment intermediate outcome. If Assumption (4.1) holds, the effect of T on M and the effect of M on Y are estimated as follows:

$$M = \beta_M^T T + \epsilon_M \quad (4)$$

$$Y = \beta_Y^T T + \beta_Y^M M + \epsilon_Y \tag{5}$$

while the IE is the product of β_M^T and β_Y^M, the DE is given by β_Y^T.[18] As discussed above, the IE recovered via equation (5) can be biased in unknown ways if Assumption (4.1) fails to hold in our data. To overcome potential bias in IE estimates due to violation of Assumption (4.1), we have conducted the following two robustness checks. First, following Hicks and Tingley (2011), we undertook a sensitivity analysis to assess the degree of violation of Assumption (4.1). This is done by checking the correlation (ρ) between the errors terms of equations (4) and (5). Assumption (4.1) holds when $\rho = 0$. Hence, large values of$|\rho|$ implies the presence of large bias in IE estimates due to violation of Assumption (4.1).

Second, following the approach of Dippel, Ferrara and Heblich (2020), we have attempted to identify the IE of nutrition knowledge without imposing Assumption (4.1) using an instrumental variable (IV) estimation strategy. As explicated in Dippel, Ferrara and Heblich (2020), the IV estimation strategy identifies IE consistently so long as the source of endogeneity is confounders that jointly influence T and M but not T and Y. As such, we use treatment assignment as an instrument (Z) to identify: (i) the IE of nutrition knowledge on OFSP adoption using access to OFSP vines from school as a measure of treatment status (which is an indicator variable that takes a value of 1 if the household reports receiving OFSP vines from school at the endline or 0 otherwise). Similarly, we also identify the IE of nutrition knowledge on OFSP consumption using OFSP adoption as a measure of treatment status. Finally, we also identify the IE of OFSP adoption on consumption using nutrition knowledge as a measure of treatment status. With this in hand, the first stage for the treatment and mediator equations is estimated as follows:

$$\begin{aligned} &\hat{T} = \beta_T^Z Z + \epsilon_T \rightarrow M = \beta_M^{\hat{T}} \hat{T} + \epsilon_M \\ &\hat{M} = \delta_M^Z Z + \delta_M^T \mathrm{T} + \epsilon_T \end{aligned} \tag{6}$$

where $\hat{T}$ is the predicted value of T in equation (6). The second stage outcome equation (i.e. the effect of M on Y conditional on T) is then estimated as follows:

$$Y = \beta_Y^{\hat{M}} \hat{M} + \beta_Y^T \mathrm{T} + \epsilon_Y \tag{7}$$

where $\hat{M}$ is the predicted value of M in equation (6). In the above regression specifications, the IE is the product of $\beta_M^{\hat{T}}$ in equation (6) and $\beta_Y^{\hat{M}}$ in equation (7), while the DE is given by β_Y^T in equation (7). We present our IE estimates with and without imposing Assumption (4.1) in Table 7. Under Assumption (4.1), considering nutrition knowledge as a mediator and OFSP adoption and consumption as outcomes, the IE estimates reported in Table 7

18 Note that despite the binary nature of both the mediator and outcomes, we used OLS as our preferred regression specification.

Table 7. Results of causal mediation analysis

	First stage: equation (4)				First stage: equation (6)		
	Knowledge		$Adoption_t$	$Adoption_{t-1}$	Knowledge		$Adoption_t$
Treatment	0.618*** (0.107)	0.814*** (0.104)	0.261*** (0.049)	0.307*** (0.048)			
OFSP access					1.29*** (0.203)		
Knowledge							0.316*** (0.057)
$Adoption_t$						3.16*** (0.057)	
	Second stage: equation (5)				**Second stage: equation (7)**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Treatment	0.157*** (0.038)	0.112*** (0.039)	0.091*** (0.033)	0.062* (0.033)			
Knowledge	0.101*** (0.015)	0.079*** (0.015)			0.217*** (0.101)	0.128*** (0.05)	0.036 (0.024)
OFSP access					0.164*** (0.074)		
$Adoption_t$			0.329*** (0.04)			0.275*** (0.045)	0.565*** (0.189)

(continued)

Table 7. (Continued)

	First stage: equation (4)				First stage: equation (6)		
	Knowledge		Adoption$_t$	Adoption$_{t-1}$	Knowledge		Adoption$_t$
Adoption$_{t-1}$				0.377*** (0.044)			
DE	0.157	0.112	0.091	0.062	0.164	0.275	0.036
IE	0.062	0.065	0.086	0.116	0.28	0.408	0.179
(%) mediated	28.4%	36.5%	48.6%	65.2%	63.1%	59.7%	83.1%
ρ at which IE = 0	0.24	0.213	0.381	0.418	–	–	–
Baseline covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	1,064	588	588	588	1,064	588	588

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical level, respectively. All regressions include strata dummies. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline. In the first four columns, we assumed that both the treatment and mediator variables are exogenous. In the next three columns, we consider both treatment and mediator variables endogenous and hence used treatment assignment as an instrument (Z) to identify IE.

suggest that indeed additional nutrition knowledge is an important mediator of both adoption and consumption outcomes. Our IE estimates suggest that nutrition knowledge mediated about 28.4 and 36.5 per cent of the treatment effect on OFSP adoption and consumption by children under 5 years of age, respectively. In column (3), we report IE estimates considering OFSP adoption status in the current production season as a mediator and consumption as an outcome. We find that adoption mediated about 48.6 per cent of the treatment effect on OFSP consumption by children under 5 years of age. However, due to the non-separability of adoption, production and consumption outcomes, OFSP consumption at time t could reflect OFSP production in the previous season. In particular, since OFSP has a short production cycle, some farmers may have grown OFSP in the previous season but not in the current season. Hence, in column (4), we report IE estimates using OFSP adoption status in the previous production season (i.e. OFSP adoption at time $t-1$) as a mediator for OFSP consumption at time t. In this case, we find that, adoption mediated about 65 per cent of the treatment effect on OFSP consumption by children under 5 years of age.[19]

In Figure 1, we also report how sensitive our IE estimates are to potential violation of Assumption (4.1) by estimating IE at different values of ρ. In all cases, we find that the correlation between the error terms of equations (4) and (5) would have to be highly positive for our IE estimates to vanish.

In columns 5–7, we report IE for nutrition knowledge and adoption without imposing Assumption (4.1). We again find that improved nutrition knowledge is an important driver of both adoption and consumption outcomes. For instance, we find that about 63.1 per cent of the school vine distribution effect on adoption is mediated via improved nutrition knowledge. Similarly, about 60 per cent of the adoption effect on OFSP consumption by children is mediated via improved nutrition knowledge, while almost the entire effect of nutrition knowledge on OFSP consumption is mediated through adoption (i.e. nutrition knowledge affects consumption only through adoption and almost no OFSP consumption by children occurred without adoption). Our results are consistent with the findings by studies that leveraged school-age children and young adults for nutrition education. For Schreinemachers et al. (2020), (2019) find that exposing children and caregivers to nutrition information simultaneously improves both nutrition knowledge- and consumption-related outcomes, whereas nudging only children improves intermediate nutrition knowledge–related outcomes but not consumption outcomes. However, our results contradict the findings by de Brauw *et al.* (2018) that show that nutrition knowledge did not matter in explaining adoption in Uganda and Mozambique. We attribute this divergence to difference in the type of channels and messengers used for delivering nutrition messages to households. Whereas de Brauw *et al.* (2018) used farmer groups as information hubs, the FT approach used

19 The estimated IE is almost identical with our IV-based IE estimates reported in column (6), suggesting that the IE estimates reported in column (3) are likely to be biased due to violation of Assumption (4.1).

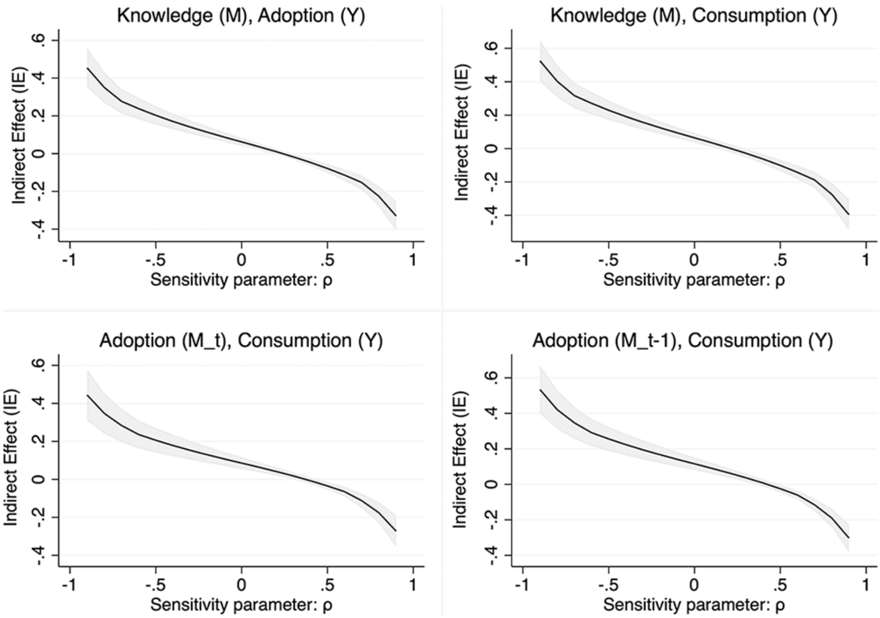

Fig. 1. Sensitivity of IE estimates.
Notes: The top panel shows the sensitivity of the IE for nutrition knowledge (i.e. columns 1 and 2 in Table 7), while the bottom panel shows the sensitivity of the IE for adoption (i.e. columns 3 and 4 in Table 7). The shaded region shows the 95 per cent confidence interval.

primary schools as information hubs, and pupils, both as targets of messages and messengers. Thus, the importance of improved OFSP nutrition knowledge as a key channel for driving adoption and consumption of OFSP might be explained by the FT's approach of exposing (training) both schoolchildren and their parents to relevant OFSP agronomy and nutrition topics.

4.6. Robustness checks

In this section, we conduct a number of robustness checks to ensure the validity of our results. First, we re-estimate our treatment effects for the main outcome variables with wild bootstrap standard errors. In our main analysis, we report standard errors clustered at the village/school level. However, these standard errors might be inconsistent when the number of clusters are few (Cameron, Gelbach and Miller, 2008). Following the approach of Cameron, Gelbach and Miller (2008), we report our main results with wild bootstrap standard errors in Table 8, which is consistent with the main results reported in Table 2.

Second, we probe how sensitive our results are to possible contamination due to the *give-double* exchanges. This robustness check is a key as some households in the control village may have received vines from households in the treatment villages due to the *give-double* exchanges or directly from

Table 8. With wild bootstrap standard errors

	OFSP adoption	OFSP fraction	Child consumed OFSP
Treatment	0.210***	0.083***	0.166***
	(0.037)	(0.028)	(0.035)
Baseline covariates	Yes	Yes	Yes
Baseline outcome	Yes	Yes	Yes
Number of observations	1,064	878	588

Notes: Wild bootstrap standard errors are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical levels, respectively. All regressions include strata dummies. All regressions include strata dummy. Baseline outcome controls are the respective baseline values of the outcomes. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

Table 9. Impact excluding contaminated observations

	(1)	(2)	(3)
Treatment	0.228***	0.228***	0.231***
	(0.044)	(0.042)	(0.038)
Baseline covariates	No	No	Yes
Baseline outcome	No	Yes	Yes
Number of observations	1,052	1,052	1,052

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical level, respectively. All regressions include strata dummies. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

schools. If such type of contamination is high, our estimates would be attenuated. In our endline survey, we find that about 24 households, close to 3 per cent of the households in control villages, reported receiving vines directly from schools. As such, we drop these households and re-estimate impacts on our main outcome of interest: adoption of OFSP. Estimation results in Table 9 suggest that our impact estimates are robust to possible contamination. However, as expected, the treatment effect is slightly higher compared to those reported in Table 2.

Third, we also report country-specific treatment effects in Table 10. In our main analysis, we use the pooled data with country fixed effects to account for country level differences. In Table 10, we report treatment effects on OFSP adoption separately for Uganda and Tanzania. Our country-specific estimates on OFSP adoption are consistent with the main estimates reported in Table 2.

Finally, we probe the robustness of our results to the seasonality of OFSP production. In our main analysis, we only considered adoption in the current production season. However, it is difficult to get consistent responses for questions referencing seasons given that some farmers grow sweet potato

Table 10. Treatment effects by country

	Tanzania		Uganda	
	(1)	(2)	(3)	(4)
Treatment	0.231***	0.235***	0.169***	0.169***
	(0.044)	(0.044)	(0.056)	(0.051)
Baseline covariates	No	Yes	No	Yes
Baseline outcome	No	Yes	N0	Yes
Number of observations	647	647	417	417

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical level, respectively. All regressions include strata dummies. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

Table 11. Impacts using alternative OFSP adoption measures

	Since 2016	Last season	Last/current season
Treatment	0.343***	0.254***	0.278***
	(0.035)	(0.034)	(0.036)
Baseline covariates	Yes	Yes	Yes
Baseline outcome	Yes	Yes	Yes
Number of observations	1,064	1,064	1,064

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical levels, respectively. All regressions include strata dummies. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

continuously, while others grow them in a semi-continuous manner. In particular, since OFSP has a short production cycle, some farmers may have grown OFSP in the previous season but not in the current season, the season that corresponds to the endline survey. For instance, at the endline, we find that the median recipient on the school list had grown OFSP for four seasons, and the median village list recipient had grown OFSP for three seasons at endline. We, therefore, consider a longer production period and measure adoption by considering adoption since 2016 (i.e. since the vines were distributed by the FT project), last production season or either in the last or current production season. As shown in Table 11, our adoption impact estimates are robust to alternative measures of the OFSP adoption indicator.

4.7. Cost-effectiveness analysis

In this section, we report cost-effectiveness estimates for the FT interventions to provide some context to the impacts associated with the FT interventions. That is, since information on the costs incurred to achieve the reported impacts of the FT interventions is critical to replicate or scale up the FT project, we weigh the costs against the benefits of the project in cost-effectiveness analysis and compare our estimates to similar projects with published results. To this end, we compare our estimates with that of the Reaching End Users (REU) project since this is the only other project for which we were able to gather information on rigorous impact measurement on OFSP uptake and cost-effectiveness after 2 years of implementation. In our setting, we report cost-effectiveness estimates in terms of cost per farmer adopting OFSP. This cost-effectiveness metric is computed by dividing the cost per vine recipient by the percentage point increase in OFSP adoption. To estimate the actual costs of FT interventions, we used the COSTAB approach that structures costs around activities. This approach is used by the World Bank to assess project costs (World Bank, 2001). Activity level costs were computed using a combination of direct analysis of financial reports and cost receipts by implementing partners. Note that our cost-effectiveness analysis is also based on the marginal cost of the FT interventions (instead of average costs as in de Brauw *et al.* (2018)), which we define as the costs that only exist because of the project. These are the cost that must be incurred if the project is to be implemented in another context. For instances, it is reasonable to assume that other areas will have school facilities that can be leveraged to deliver the FT project interventions (so schools are not included in marginal cost), but vines must be purchased and delivered to schools, so vine and transportation costs are included.[20]

Table 12 summarises the estimated benefits and costs of the FT interventions. While the number of primary beneficiary households per school was estimated based on the number of students that received vines through school distribution, the number of secondary beneficiary households was estimated based on year three data from project monitoring information system (MIS). With the FT interventions increasing OFSP adoption by 21 percentage points, the number of total adopters per school is estimated at 135 households. Based on average benefit and cost figures, the estimated cost of the FT project per OFSP adopting household is about US $59, with estimates varying between 43 and 77 USD depending on local prices and other factors such as distance

20 Note that although the FT interventions might have delivered other benefits, we focus on the adoption of OFSP, which we rigorously estimate in this study as a measure of project benefit. In addition, the decision on whose costs to include (viewpoint) can substantially impact cost estimates. For instance, whereas the funder's view of costs, which includes cost captured in the project budget (the grant amount, in this case), excludes contributions by implementing partners who might have mobilised additional resources, the implementer's view considers input cost (time and money) incurred by all implementers. On the other hand, the social view combines both implement and funder views, as well as cost by other partners tangential to the project, such as other education officials. Our main cost approach follows the implementer view.

Table 12. Cost-effectiveness analysis

	Number of beneficiary households
Primary beneficiaries per school	200
Secondary beneficiaries per school	442
Total beneficiaries per school	642
OFSP adopters per school (primary + secondary)	135
	Cost estimates (USD)
Cost per total beneficiary household (primary + secondary)	12.43
Cost per primary beneficiary household	39.89
Cost per school	7,979
	Cost-effectiveness (USD)
Cost per household adopting OFSP (primary + secondary)	59.52

to targeted schools or the need to hire additional vehicles for supervision. The REU project reported about US $100 cost per adopting household in Uganda (de Brauw *et al.*, 2018). An important caveat to this comparison is that the REU project used the average cost of project implementation, while the FT project used marginal cost of project implementation.

The higher cost-effectiveness of the FT compared to REU stems from two sources. First, the cost of FT per primary vine recipient is much lower, at around US $39.89 vs $132 for REU in Uganda. Second, FT achieved increased dissemination of vines from primary recipients to other members of the community. Unlike FT, there was no emphasis on formal vine sharing, and schools did not play a role in the REU project. FT recipients distributed vines to an average of 2.2 other households compared to 1 in the REU project in Uganda. By only distributing to schools, FT limited the logistical burden associated with transporting vines to many drop-off points. Furthermore, FT did not need to identify and support farmer groups prior to vine distribution, limiting pre-distribution costs. The project did not have to maintain a complicated voucher or sales system and only had to arrange one-off bulk purchases. Despite its relatively lower cost-effectiveness, it is important to keep in mind that the REU outperformed the FT approach when it comes to coverage. While FT interventions achieved a 21 percentage point increase in the likelihood of farmers growing OFSP among primary recipients, the REU project in Uganda achieved a 62 percentage point increase in likelihood of OFSP adoption.[21]

21 Also, note that the REU project distributed approximately about 1,000 vine cuttings per household, while the FT distributed only 120 starter packs of sweet potato vine cuttings per household. Hence, given the vegetatively propagated nature of the crop, such differences in the scale (quantity) of vine distribution makes comparison, in terms of both adoption impacts and cost-effectiveness, difficult. In addition, there were also important measurement-related issues due to the seasonality of sweet potato cultivation. In fact, as reported in Table 11, when we consider a longer production period and measured adoption by OFSP cultivation since 2016 (i.e.

4.8. Impact on compliers

Given that our sampling design for evaluation was blind to the specific households that received FT interventions and due to its policy relevance, we reported ITT estimates in Tables 2 and 6 for OFSP adoption and consumption outcomes, respectively. However, the ITT average impacts across treated households who actually received the FT interventions and those who did not. In this section, we report the LATE focusing on OFSP adoption and consumption outcomes. This is particularly important in our case since not all eligible households received the FT interventions. For instance, from the endline survey, we find that 66 per cent of the households in the treatment villages (i.e. about 80 per cent of the households on the school list and 56 per cent on the village list) reported receiving OFSP vines.[22] Less than 100 per cent rate in the school list could be due to recall issues or distribution issues or issues with vines making it from the school to the household. For instance, some of the children who received vines may have failed to take the vines back to their parents or some of the students may not have been present during vine distribution day at the school. FT also organised dedicated OFSP nutrition education for children in schools and households in treatment villages, with 44 per cent of the households reporting that children have delivered nutrition messages to them at the endline.

Hence, even if the treatment assignment was randomised, access to the specific interventions offered by the FT project among households in treatment villages may not be random. That is, even though we demonstrate that baseline OFSP vine and nutrition training access was balanced between treatment and control groups (see, Table 1), we cannot rule out selection bias in individual's access to OFSP vines and/or nutrition training in treatment villages (i.e. while treatment status is random, access/receiving vines is not as it is based on endogenous household decisions). As such, we report LATE estimates using treatment assignment as an instrument for access to the specific FT interventions. In particular, we measure access to FT interventions using the following indicators: (i) access to OFSP vines, which is an indicator variable that takes a value of 1 if the household reports receiving OFSP vines since March 2016 at the endline or 0 otherwise; (ii) access to both OFSP vines and nutrition training, which is again an indicator variable that takes a value of 1 if the household reports receiving both OFSP vine and nutrition information at the endline or 0 otherwise.

LATE estimates reported in Table 13 consistently show positive and significant impacts on OFSP adoption and consumption outcomes among individuals that received the FT interventions. For instance, depending on the way treatment status is defined, we find about 47–59 percentage point increase in the

since the vines were distributed by the FT project), the estimated treatment effect on adoption becomes 0.343, up from the 0.21 treatment effect reported based on OFSP cultivation in the current production season.

22 Note that at baseline, about 68 per cent of the households in the village list had at least one child enrolled in primary school so many households on the village list received vines directly from the school through their children.

Table 13. IV estimates

	OFSP adoption	OFSP fraction	Child consumed OFSP
OFSP vines	0.471***	0.191***	0.347***
	(0.065)	(0.055)	(0.072)
OFSP vine + nutrition	0.592***	0.225***	0.452***
	(0.095)	(0.071)	(0.092)
Baseline covariates	Yes	Yes	Yes
Baseline outcome	Yes	Yes	Yes
Number of observations	1,064	878	588

Notes: Standard errors clustered at the village level are reported in parentheses. ***, ** and * indicate significance at the 1, 5 and 10 per cent critical level, respectively. All regressions include strata dummies. Baseline covariates include variables reported in Table 1: age, education, dummy variable for having received vines at baseline, dummy variable for growing sweet potato at baseline and dummy variable for having received training about sweet potato cultivation at baseline.

probability of growing OFSP among compliers at the endline. Similarly, the LATE on OFSP fraction shows about 19–23 percentage point increase, which again is about threefold times larger than the ITT estimates reported in Table 3. Finally, the LATE on OFSP consumption by children under 5 years of age, which shows between 35 and 45 percentage point increase in consumption, is also much higher compared to the ITT reported in Table 6.

5. Conclusion

In this paper, we present evidence from a RCT experiment that tested the efficacy of an innovative approach to getting new agricultural technologies to rural households across Tanzania and Uganda. The approach relies on primary schools in rural areas as hubs for distributing starter packs of sweet potato vines to pupils to take home to their parents. Vine distribution was accompanied by sweet potato cultivation and nutrition training of farmers and schoolchildren. Our results show that 2 years after the initial vine distribution, households in treatment villages are 21 percentage points more likely to report growing OFSP and 27 percentage points more likely to correctly state the nutritional benefits of OFSP compared to those in control villages. We also find up to 16 percentage point increase in the likelihood of OFSP consumption by children under 5 years of age in treatment villages compared to those in control villages. Using causal mediation analysis, we show that up to a third of the observed treatment effect on OFSP adoption and consumption outcomes is mediated by improved knowledge about the nutritional benefits of OFSP.

The findings from this study suggest that schools can play a critical role in accelerating the diffusion of certain types of agricultural technologies in rural areas. This is an important finding since schools in rural communities are central to community life. In Tanzania and Uganda, primary school education is free and mandatory, which makes it possible to reach a diversity of community members. Furthermore, in both countries, there is a fair amount of nutrition teaching in the curriculums, which creates an opportunity to channel and share information about agricultural innovations. By relying on this established mode of engagement between rural households and schools, the evidence reported in this paper suggests that interventions that promote food-based solutions to addressing micronutrient deficiencies can rely on pupils for messaging to boost the cultivation and consumption of micronutrient-rich food crops. Therefore, future projects working with sweet potato or other similar vegetatively propagated crops such as cassava may consider adopting the FT's school-based distribution system.

Nonetheless, there are important limitations, primarily from the perspective of the external validity of the adoption and cost-effectiveness estimates reported in this study. First, generalising our findings to other crops may not be possible due to the unique biological and economic characteristics of vegetatively propagated crops: they are difficult to distribute, easy to share and seldom part of a commercial seed system. In this regard, further research will be necessary to confirm the generalizability of the FT distribution model for other crops and in different contexts. Second, we identified increased nutrition knowledge as an important mediating channel to drive OFSP adoption and consumption outcomes, which is apparently not so for the traditional extension-based approach (de Brauw *et al.*, 2018). While this divergence may be attributed to the difference in the type of channels and messengers used for delivering nutrition messages, it may also point towards a different 'quality' of such effects, which may turn out to be more resilient. In this regard, it would be interesting to evaluate the persistence and sustainability (long-term impacts) of the FT and REU distribution models. Third, although we compare the cost-effectiveness of the FT approach with the REU approach, we are aware that such comparison could be misleading because of external validity concerns. Convincing cost-effectiveness analysis can only be done by evaluating the efficacy of alternative distribution options within the same experiment. Future research that aims to assess the effectiveness of schools as hubs for agriculture technology and information diffusion should thus consider juxtaposing this approach with other channels such as farmer groups or established public extension systems within the same experiment. Finally, future studies could consider an extended range of outcomes related to the school-based distribution approach. For example, research can look at the impact of the FT approach on education outcomes such as school attendance or performance in exam scores.

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Supplementary data

Supplementary data are available at *ERAE* online.

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