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ORIGINAL ARTICLE

Group-based and citizen science on-farm variety selection approaches for bean growers in Central America

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Abstract

Participatory approaches for crop variety testing can help breeding teams to incorporate traditional knowledge and consider site-specific sociocultural complexities. However, traditional participatory approaches have drawbacks and are seldom streamlined or scaled. Decentralized on-farm testing supported by citizen science addresses some of these challenges. In this study, we compare a citizen science on-farm testing approach — *triadic comparisons of technology options* (tricot-PVS) — with the benchmark state-of-the-art group-based participatory variety testing approach (group-PVS) over a set of socioeconomic outcomes. We focus on on-farm testing of common bean (*Phaseolus vulgaris* L.) in the Trifinio area of Central America. We measure the impact of these two approaches on bean growers in terms of on-farm diversification and food security. We use data from 1978 smallholder farmers from 140 villages, which were randomly assigned to tricot-PVS, group-PVS or control. Utilizing a difference-in-difference model with inverse probability weighting and an instrumental variable approach, we observe that farmers involved in group-PVS, and tricot-PVS had comparable levels of on-farm varietal diversification with respect to control farmers. Nonetheless, group-PVS appears to be significantly more effective in boosting household food security, which can be attributed to improved agronomic management of the crops. This study contributes to the next generation of innovations in exploring trait preferences to produce more inclusive, demand-driven varietal design that democratize participatory varietal selection programs.

KEYWORDS

citizen science, food security, on-farm varietal diversification, participatory variety selection, tricot approach

JEL CLASSIFICATION

O13, O35, Q01, Q16

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1 | INTRODUCTION

Farmers often face tough barriers to adopting new varieties, when farmers' knowledge, habits, and traditions are not addressed in trials (Snapp et al., 2019). When farmers fail to adopt new varieties, they may not receive benefits such as heightened food security (Kaliba et al., 2018), dietary quality (Qaim, 2020), and on-farm agrobiodiversity for risk management (van Etten et al., 2019).

Participatory varietal selection engages farmers to test genetically distinct products developed by plant breeders, thus increasing the probability of adoption (Ceccarelli, 2015; Ceccarelli & Grando, 2020, 2007). Farmers are directly involved in numerous research activities, including selecting seeds, observing pests and crop diseases, and evaluating research products (Rhoades & Booth, 1982; van de Gevel et al., 2020). However, in pursuing local relevance, farmer participatory projects often reach a relatively small number of farmers who may not be fully representative of the total population (Farrington & Martin, 1988). Furthermore, participatory approaches are perceived as lacking in effectiveness if selection is not done on farms (Cobb et al., 2019).

Decentralized on-farm testing supported by citizen science may address these two issues and revive participatory varietal selection (van de Gevel et al., 2020). In agriculture, citizen science engages farmers in experimentation and observation at scale, making use of digital media to obtain higher levels of end-users' involvement (Minet et al., 2017; Ryan et al., 2018). Our study focuses on an innovative decentralized citizen science approach called triadic comparison of technology options (or tricot, van Etten et al., 2016). In this article we describe tricot as tricot-PVS to discriminate from the group-based participatory variety selection approach (group-PVS).

The tricot-PVS approach has demonstrated to improve variety recommendations and genotype selection in challenging environments (de Sousa et al., 2021; van Etten et al., 2019). Farmers individually evaluate a set of genotypes (pre-release breeding products, varieties, or parents) acting as citizen scientists for their own on-farm experiment. Being largely decentralized and relatively less time-consuming than traditional participatory variety selection programs (van Etten et al., 2019), tricot-PVS experiments can collect a vast number of variety evaluation datapoints across large areas. Evidence shows that this approach produces robust comparative data, enables farmers to observe crops throughout the cropping season on their own farms, and increases the number of participating farmers incurring the same costs (van Etten et al., 2019). Nevertheless, there is no evidence on how the effects of the tricot-PVS approach on socioeconomic outcomes compare with alternative participatory varietal selection approaches. In this study, we are interested in investigating whether tricot-PVS led to higher on-farm varietal diversification and household-level food security in the medium-run (i.e., 3 years after the experiment), compared to the state-of-the-art participatory varietal selection. This contributes to the discussion around participants' benefits from participatory plant breeding beyond the development of client-oriented improved varieties, in line with Sustainable Development Goals 2 (Zero Hunger) and 13 (Climate Action).

There is ample evidence on the efficiency and effectiveness of group-PVS compared to non-participatory approaches (Ceccarelli, 2015; Ceccarelli & Grando, 2020; Johnson et al., 2003). Group-PVS can support marginalized communities to make their own varietal decisions (Chambers, 1994) and it is shown to have positive effects on both varietal diversification (i.e., intra-specific diversity) (Gotor et al., 2021) and crop diversification (i.e., inter-specific diversity) (Asfaw et al., 2019; Waha et al., 2018). Varietal improvements supported by group-PVS have a longer time horizon of usage, as the short-term objectives of the researchers are counterbalanced by the farmers' long-term horizon of actions (van de Fliert & Braun, 2002). Furthermore, group-PVS has been directly linked with enhancing food security levels among participating households, thanks to the improved yields and stress tolerance of the new varieties (Joshi & Witcombe, 1996; Joshi et al., 2012).

However, the assumption that decentralized citizen-science approaches like tricot-PVS can generate positive effects on diversification and food security needs testing. Gotor et al. (2021) offered the first and only study to investigate effects of tricot-PVS in the Bihar zone of India. The study found that tricot-PVS leads to higher on-farm diversification which results in higher crop productivity and adaptive capacity. Our work begins to close this research gap by comparing the tricot-PVS approach with group-PVS, benchmark among the participatory approaches. Tricot-PVS and group-PVS both supply breeding programs with more (and early-stage) information that can feed into their breeding efforts (van Etten et al., 2019). However, it is less clear how these two approaches differently benefit the farmers engaged. This study explores whether or not (i) tricot-PVS participants show a higher degree of on-farm varietal diversification than group-PVS participants when compared to control farmers, and whether (ii) participation in the tricot-PVS approach increases household food security.

We randomly assigned 1978 smallholder common bean (*Phaseolus vulgaris* L.) growers in the Trifinio area (a cross-boundary zone between Guatemala, Honduras, and El Salvador) to three groups: tricot-PVS, a benchmark state-of-the-art group-based PVS approach (group-PVS), and a control group (i.e., farmers who were not invited to take part in the participatory approaches). We build a panel dataset, collected at baseline (2015) and endline (2018), to quantify the effects of tricot-PVS and group-PVS on on-farm diversification and food security. To mitigate possible endogeneity and selection biases, we run a difference-in-difference model with inverse probability weighting and an instrumental variable approach. We find that group-PVS and tricot-PVS lead to comparable improvement in on-farm varietal diversification compared to the control group. Nonetheless, group-PVS appears to be more effective in decreasing households' food insecurity. To rationalize the mechanisms behind these findings, we analyze how adoption, yield and quality of seeds delivered change between tricot-PVS and group-PVS.

The remainder of the article is structured as follow: Section 2 presents the study's conceptual framework, linking PVS methods to expanding on-farm varietal diversity and strengthening household food security. Section 3 describes the study context, while Section 4 specifies the estimation strategy. Sections 5 and 6 present results and discussions of this study, respectively. Section 7 offers conclusions from the study, and presents respective policy implications.

2 | CONCEPTUAL FRAMEWORK

We hypothesize the effects on on-farm varietal diversification to be positive for two participatory approaches: in both groups, participants benefit from testing, evaluating, and eventually adopting new varieties. Witcombe et al. (2001) and Gotor et al. (2021) find a positive correlation between intra-varietal diversity and group-PVS participants, while Witcombe et al. (1996) state that the long-term effect of group-PVS is to increase intra-varietal diversity, but where indigenous variability is high it can also reduce it. Whether the effect of on-farm varietal diversification is stronger for tricot-PVS or group-PVS is an open question. Tricot-PVS participants can test three new varieties directly on their own plot, while group-PVS participants have the opportunity to observe all the varieties on a common trial plot. The on-farm decentralized experience within tricot-PVS might encourage farmers to retain seeds for on-farm multiplication and usage, but the three varieties tested are assigned randomly and not chosen by participants. On the other hand, group-PVS participants are exposed to a wider set of options, but the lack of on-farm testing might act as a deterrent for further uptake and intra-variety diversification in the medium-run.

The hypothesis on food security is also characterized by trade-offs. Joshi et al. (2012) and Tiwari et al. (2010) find that the testing of new varieties through group-PVS can contribute to food security, thanks to the inclusion of marginalized actors in the evaluations (mainly women and vulnerable populations). van Etten (2011) and Richards et al. (2009) claim that also crowdsourced citizen science methods lead to higher food security, increasing the local adaptability and accuracy of the varieties which are on offer. Given the decentralized variety testing approach which characterizes tricot-PVS, we hypothesize higher adoption and yields among tricot-PVS participants, as varieties are tested directly in farmers' fields, management practices, and agro-ecological conditions. This might lead to higher food security among tricot-PVS farmers. However, group-PVS frequently involves agronomic training, and it is characterized by a higher number of interactions among technical staff and farmers, which can be expected to result in a larger knowledge gain by both parties. This might lead to a yield increase that is more pronounced for group-PVS than tricot-PVS, and therefore comparatively higher food security.

Further, exogenous to farmers, the program may deliver the variety which farmers selected as preferred, which will consequently impact on-farm varietal diversity and food security, through adoption and yield. This ability is program-dependent, and we hypothesize group-PVS excelling tricot-PVS in delivering the preferred variety as the number of engaged farmers is lower. However, the accuracy of variety testing benefits from the decentralized testing locations at farmers' site, typical of tricot-PVS.

The relations underlying our hypotheses are exemplified in Figure 1a.

3 | STUDY SETTING

This research was performed in the Trifinio area (a cross-boundary zone between Honduras, Guatemala, and El Salvador). Trifinio is a transboundary region that is managed through a special tri-national authority to promote cross-border cooperation and integration, and biodiversity and resource conservation (Celata et al., 2013; MARN, 2010). Trifinio region covers an area of 7541 km^2, administrated by 45 towns. The region has roughly equal shares of territory in Guatemala and Honduras, and the remaining 15% belongs to El Salvador. The area is predominantly rural. More than half of its estimated 670,000 people are illiterate. Although 80% of the area has forestry potential, only 18% of its forest area remains intact. It contains the sources of the Lempa river, which is shared by the three countries. It is mainly semiarid, with 75% of the area located on slopes exceeding 25%. The average annual precipitation ranges from 500 to 1600 mm, the average temperature from 15 to 25°C and the evapotranspiration from 900 to 1600 mm. The altitudinal ranges are 600–1600 m

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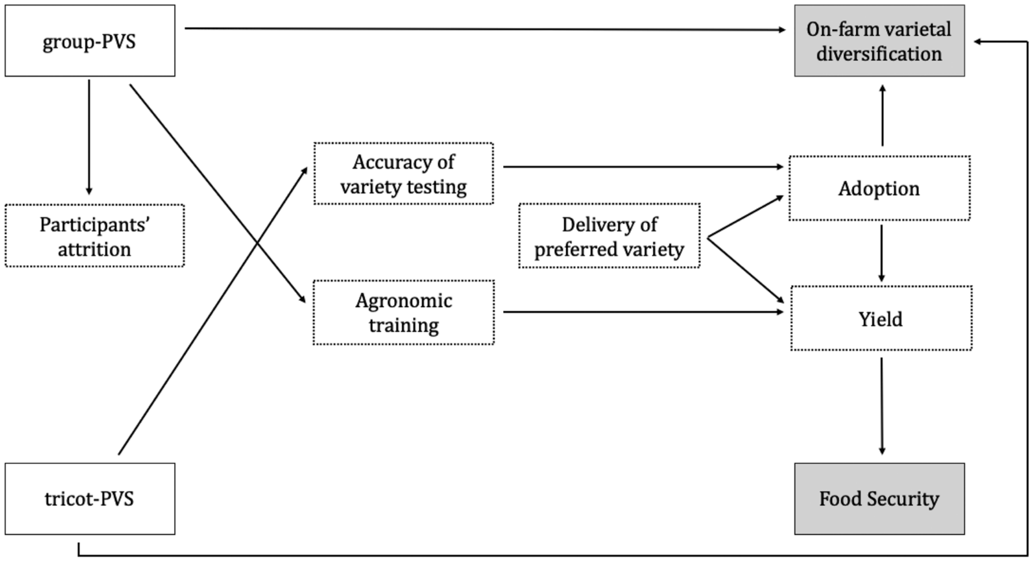

FIGURE 1 Hypothesis and mechanisms of the study. Dotted boxes highlight mechanisms while the grey box signals the outcome variables.

above sea level. Agricultural activity occurs primarily through small, single-family plots, and most of the land is devoted to subsistence crops (mainly corn and beans), and coffee for commercial purposes (GIZ, 2011). In this study, we focus on common bean (*Phaseolus vulgaris* L.). The reason is twofold: in this area, up to 86 different varieties of beans are used, including improved and local ones (GIZ, 2011). Farmers regularly grow beans on their plot, which makes the crowdsourced citizen science approach easier to implement. Furthermore, national breeding programs have the mandate to develop more client-oriented breeding projects on common beans.

This study focuses on this territory, given the evidence dearth on participatory varietal selection approaches and their impacts in Central and South America (Occelli et al., 2023) and the acute food insecurity characterizing part of Trifinio (IPC Global Unit Report., 2021). Community-based and participatory interventions are not new in the area but are usually related to water and forest management (Jennewein & Jones, 2016; Schlesinger et al., 2017).

3.1 | Sampling strategy and treatment implementation

The sample size was planned to provide an 80% chance of correctly rejecting the null hypothesis that no difference exists between treatments, with a .05 confidence interval. However, baseline information on the entire population of bean growers was not available in the area, and we based our estimates on rosters which national breeding programs use to select growers for participatory field trials. We followed a two-stage random sampling procedure. First, we selected villages from a list of villages where the national breeding programs operate. Selection criteria included the presence of at least 40 households in the village, and the presence of a known village organization able to provide training for households in any of the two treatments. In each village, we randomly selected households based on predetermined quotas from lists of households provided by the village organizations. The quotas were calculated based on the available budget for each treatment experiment. If a household could not be found (due to demise or migration) or household members could not be interviewed after three attempts, it was replaced with another household following a predetermined order.

The study involved 1978 households from 140 villages across the study area (Figure 2). Villages were randomly assigned to either group-PVS, tricot-PVS or control and then households within villages were allocated to the assigned treatment. In total, 394 households (23%) were assigned to the group-PVS approach, 739 households (35%) were randomly assigned to the tricot-PVS approach, and 845 households (42%) were assigned to the control group, where no intervention was performed. By design, farmers involved in the tricot-PVS treatment are almost double those involved in the group-PVS treatment. The tricot-PVS treatment was cheaper and required less dedicated staff. Therefore, an unbalanced design was expected to produce greater statistical power with the same resources (Liu, 2003).

In 77 out of 140 villages (55%), farmers belonging to one of the treatment groups and farmers assigned to the control groups were co-villagers. This was designed to capture spillover effects within villages. Therefore, we distinguish two types of control farmers: control farmers in villages

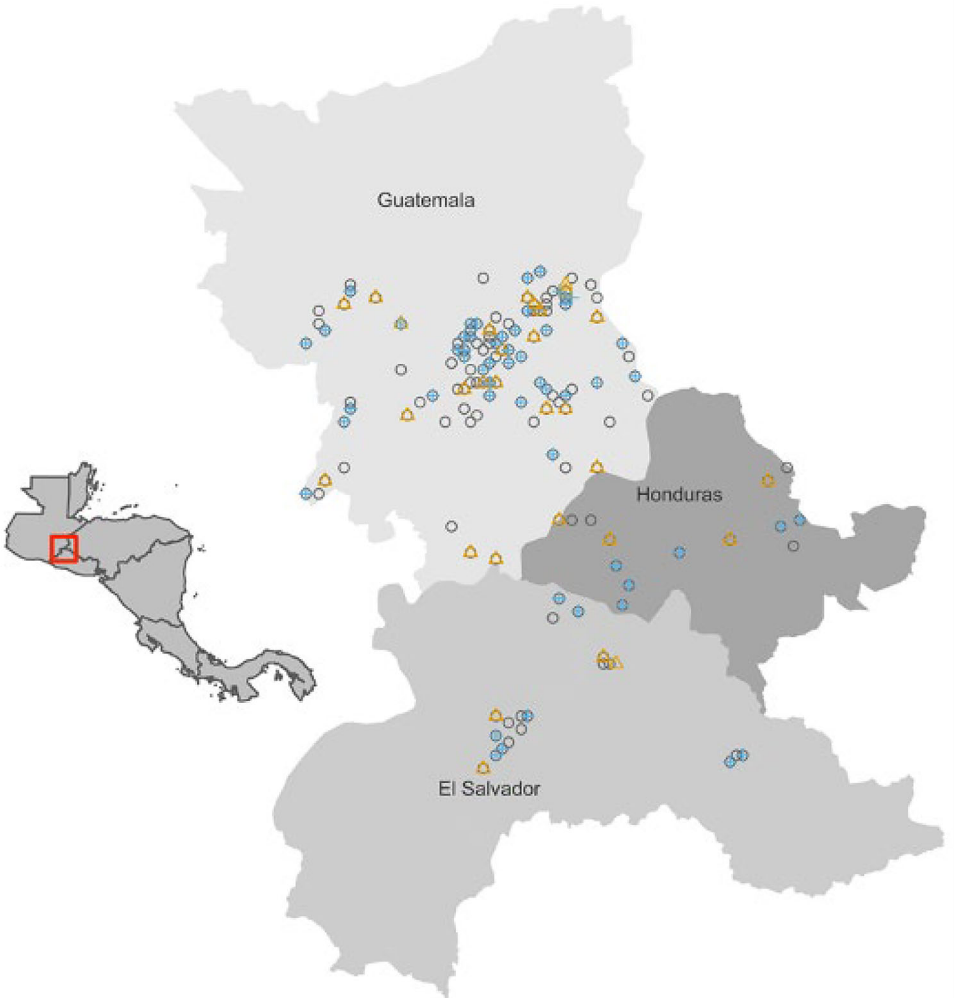

FIGURE 2 Location of interviewed households. Control (grey dots) = control households, no intervention; group-PVS (orange triangle) = intervention with state-of-the-art participatory variety testing; and tricot-PVS (blue cross) = intervention under the citizen science on-farm testing approach. In 77 villages, control farmers co-existed with treated farmers.

TABLE 1 Summary of participants, by treatment groups.

Treatment	Farmers n.	Label
Group-PVS	394	T1
Tricot-PVS	739	T2
Control—in—Control	521	C_C
Control—in—Treated	324	C_T

where only the control group was present, and control farmers in villages where farmers assigned to a treatment were present too. Control farmers in control villages are 521, while control farmers in treatment villages are 324. A summary of the four groups is reported schematically below (Table 1).

After randomization, the community organizers visited the group-PVS and tricot-PVS households and engaged them in research according to the protocols that will be described in the following sections.

3.2 | Treatment descriptions

The group-based Participatory Variety Selection (group-PVS) was selected to represent a state-of-the-art PVS approach. Group-based approaches are commonly used, despite their pitfalls (Misiko, 2013). We therefore opted to implement a group-based approach that would be as attractive as possible to farmers, as a competitive benchmark. In each village assigned to the group-PVS approach, a group of 15 selected households was formed. Two members per household were invited to participate. Participants gathered on a common plot established in their village to observe and evaluate 19 bean varieties (see the traits in Tables A1 and A2 in the Appendix). Farmers evaluated varieties by expressing their preferences simultaneously, utilizing five stones to report a score from one to five. This method did not require any level of literacy from the participants.

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Evaluation scores were then digitally transcribed and elaborated, and results subsequently shared with the evaluating farmers during plenary focus group discussions (FGDs). In FGDs, farmers elaborated on the impressions and preferences expressed, while acquiring knowledge from the other participants on their preferences and evaluations. After these group discussions, farmers expressed their preference for the bean variety they wished to receive (1.5 kg of seed). This treatment involved the participants in six meetings, accompanied by five field visits to the centralized trial. Sessions were designed to allow a continuous interaction between farmers and technical field staff (extension officers). Trainings included modules on bean agronomy and gender inclusion. The entire PVS process lasted an average of 70 days.

In the tricot crowdsourced citizen science (tricot-PVS) approach, groups of 20 farmers were selected in each village (van Etten et al., 2019). Each farmer was randomly assigned and asked to evaluate three out of 19 varieties proposed by the breeders (Appendix, Table A3). Tricot-PVS follows an incomplete block design with a block size of three varieties. While each farmer evaluates a different set of varieties, altogether all varieties are evaluated. The tricot-PVS trial was designed using the ClimMob Platform (Quirós et al., 2024).

To start the tricot-PVS experimentation cycle, farmers were invited to a central location where they participated in an initial workshop and received training, including on how to plant the trial and fill the observational card to collect evaluation data. Cards were developed to be easy to interpret, even for illiterate participants (see illustrative cards, Figure A1c in the appendix). The instructions for individual plots were that (i) the three varieties were planted on the same day next to each other, (ii) the varieties were planted with the same density of subplots of the same size, and (iii) the boundaries between one variety and another were clearly marked. During the training day, incentives for and benefits of participation were clearly explained (van Etten et al., 2019). The approach required four data collection moments by farmers (see Appendix, Table A2). Farmers recorded the evaluations on the assessment cards and technicians recorded the information digitally on the ClimMob platform (see https://climmob.net/blog/) via phone calls. Trial results were processed automatically by the ClimMob platform to produce individual reports and an overall analysis combining the data from all on-farm trials. Individual reports were shared with the farmers in a final joint meeting (one per village), in which farmers could also express their preferences for receiving 1.5 kg of seed of one of the varieties. Harvested grain from the experimental plots are kept by the participating farmer.

Despite sharing a common participatory nature, the approaches differ in five main features: (i) the total time required for farmers' engagement in in-person meetings, which is much higher in group-PVS; (ii) the degree of decentralization of the approaches, with tricot-PVS being a highly decentralized testing experiment happening directly at farmers' plots; (iii) the attention to bean agronomic management, which predominates more in group-PVS meetings; (iv) the number of varieties evaluated directly by each farmer, which is higher for group-PVS due to the triadic comparison nature of tricot-PVS, and finally, and (v) the cost of the approach, which is significantly lower in case of tricot-PVS. A summary of the cost analysis of the two approaches is summarized in Table A7 of the Appendix. Tricot-PVS costs 28% less than the group-PVS approach.

3.3 | Farm household survey

In 2015, before starting to implement the approaches, a baseline survey captured the socioeconomic status of participating farmers. In 2018, a second survey aimed at collecting data to assess the impact of the two variety testing approaches using several indicators. In both cases, the household head was the survey respondent.

The questionnaire included socioeconomic, food security, bean agronomic and varietal knowledge, and production information, and was integrated with questions from RHoMIS (Rural Household Multiple Indicator Survey) (Hammond et al., 2017). Data from the surveys were recorded electronically using Open Data Kit (ODK). Location points (latitude and longitude) were also recorded.

3.4 | Outcome variables

To measure on-farm varietal diversification, we used two indices of on-farm bean diversification: the variety count and the variety richness index. The former is a straightforward count of the total number of bean varieties grown by the household before and after the intervention, in line with studies by Torheim et al. (2004), Kumar et al. (2015), and Shively and Sununtnasuk (2015). The bean variety richness index is instead a revisited version of the Margalef index, accounting for the on-farm area planted to beans (Di Falco & Chavas, 2009; Smale et al., 1998). Following Sibhatu et al. (2015), the bean variety richness index is computed as:

$$\textit{Bean variety richness} = s/A \tag{1}$$

where s is the number of bean varieties grown, and A is the total area planted to beans (in hectares). For both indices, higher values indicate higher on-farm bean varietal diversity. We built these indices starting from two questions: the number of bean varieties grown at date of survey and the total area planted to beans.

Since only 3 years had elapsed from the end of the experiment to the endline evaluation, it is likely that farmers are still evaluating the new variety. They might be in a transition stage when diversification is always higher; nonetheless, as this stage is common among all farmers, we do not address this point in this work.

To estimate household food security, we used the Household Hunger Scale (HHS) (Ballard et al., 2011), which captures combinations of different behavioral and psychological dimensions of the food insecurity experience (Maxwell et al., 2014). The scale was designed to capture household behaviors signifying insufficient quality, quantity, acceptability, and anxiety over insecure access. Unlike other household food insecurity indicators, HHS has been specifically developed and validated for cross-cultural use, making it highly suitable for our region of study, which incorporates three different countries. In the Appendix, we include the survey module that captures the HHS indicator (Appendix, Section 4).

As suggested by Ballard et al. (2011), answers given to questions in this module are combined by simple addition into a food insecurity score with a scale from 1 to 3. The score gives increasing values to higher levels of food insecurity at household level. The values stand for: (1) Little to no hunger in the household, (2) Moderate hunger in the household, and (3) Severe hunger in the household. For this index, higher values mean less food security at household level.

To conclude, we are interested in investigating possible pathways linking on-farm varietal diversification and food security with participatory approaches. This is in line with recent changes in randomized control trial (RCT) studies, where investigating causal mechanisms acquires the same importance of inference (Banerjee et al., 2016). We do so by analyzing adoption, yield, and ability of the approach to multiply and deliver tested seed varieties. We start by defining as adopter those farmers who declare at endline to have adopted and planted a variety received by either participating in the group-PVS or the tricot-PVS approach. This is a strict definition of adoption. It is not sufficient for a farmer to simply possess the proposed variety 3 years after the experiment to qualify as an adopter; but they must be growing and harvesting it. We proceed by constructing a dichotomous variable defining the ability to produce and deliver the preferred varieties by each of the two approaches, which assumes a value of 1 when the post-experiment records confirm that either group-PVS or tricot-PVS participants have received the exact variety they have selected as best-performing during the participatory approach. This is exogenous to farmers, and it captures whether the participant was delivered with the preferred and selected variety. Lastly, yield is computed as the total harvest of the two growing seasons preceding the interviews — two growing seasons in 2014 for the 2015 survey, and two growing seasons in 2017 for the 2018 survey — divided by the total bean field size summed across the two preceding seasons.

3.5 | Covariate balancing

The baseline characteristics are relatively balanced across the control and treatment groups; nonetheless, a few differences emerge (Table 2). If we compare group-PVS participants and control farmers, the former group includes a higher number of women interviewed (+8%), a lower number of literate farmers (−7%) and a higher number of food insecure participants (+5%). Compared to control farmers, tricot-PVS participants have a higher weekly consumption rate of beans (.30 kg/week) but show higher numbers of food insecure participants (+7%). Furthermore, a higher share of tricot-PVS farmers compared to control farmers do not own their land (−5%). Differences between tricot-PVS and group-PVS participants are also partially present at baseline: tricot-PVS participants have more land for productive activities (+.14ha) and consume more beans weekly (−.22 kg) compared to group-PVS participants. Moreover, more tricot-PVS participants have higher illiteracy levels compared to the group-PVS participants (+7%).

To reduce any possible bias, we rely on a difference-in-difference estimator to evaluate the treatment effect and control for baseline differences in the regression models. The estimation strategy is detailed in Section 4.

3.6 | Attrition

Attrition was defined for different steps in each approach, depending on the reasons for farmers not participating or providing data. Individuals that did not attend any of the group-PVS training sessions were considered as if they had left the study, and are classified as affected by group-PVS self-induced attrition. On the other hand, group-PVS trials were not established for 16% of randomly-assigned group-PVS beneficiaries because of project logistics. These individuals are considered as if they were not treated and are classified as project-induced attrition. Within the tricot-PVS treatment, those that were not contacted were considered as if they did not receive the treatment and represent 5% of the beneficiaries that were randomly

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TABLE 2 Summary statistics among treatment groups at baseline.

Variable	All	Control	group-PVS	tricot-PVS	Delta tricot-PVS, control	Delta group-PVS, control	Delta tricot-PVS, group-PVS
Annual Sales (kg)	35.94	33.10	24.44	44.31	11.21	−8.66	−19.87
	(253.4)	(7.51)	(11.23)	(10.8)	(12.76)	(14.99)	(18.51)
Land for productive activities (ha)	.94	.94	.83	.97	.03	−.11	**−.14***
	(1.11)	(.04)	(.05)	(.04)	(.05)	(.07)	(.07)
Annual purchase(kg)	21.71	19.62	24.00	23.51	**3.89***	4.38	.49
	(49.84)	(1.45)	(2.9)	(1.95)	(2.37)	(3.08)	(3.60)
Proportion of households with only women	.12	.13	.11	.12	−.01	−.02	−.01
	(.33)	(.01)	(.02)	(.01)	(.02)	(.02)	(.02)
Proportion of households with a couple	.82	.81	.82	.84	**.03***	.01	−.02
	(.38)	(.01)	(.02)	(.01)	(.02)	(.03)	(.02)
Age of the head of household	44.51	44.91	43.76	44.29	−.62	−1.15	−.53
	(13.63)	(.48)	(.87)	(.52)	(.71)	(.99)	(.99)
Proportion of interviewees who were women	.55	.52	.60	.46	**.06*****	**.08*****	.14
	(.50)	(.02)	(.03)	(.02)	(.02)	(.03)	(.03)
Proportion of people with debts	.20	.25	.16	.15	**−.10***	−.09	.01
	(.40)	(.04)	(.06)	(.04)	(.05)	(.07)	(.07)
Number of people in households	5.49	5.36	5.47	5.65	**.29*****	.11	−.18
	(2.42)	(.08)	(.14)	(.09)	(.11)	(.16)	(.16)
Weekly consumption of beans (kg)	2.87	2.75	2.83	3.05	**.30*****	.08	**−.22***
	(1.77)	(.05)	(.10)	(.07)	(.08)	(.11)	(.12)
Proportion of households with children under 13 years old	.78	.74	.79	.81	**.07*****	**.05***	−.02
	(.42)	(.01)	(.02)	(.01)	(.02)	(.03)	(.03)
Proportion of people with complete primary school	.21	.22	.20	.19	−.03	−.02	.01
	(.40)	(.01)	(.02)	(.01)	(.02)	(.03)	(.03)
Proportion of people able to read and write	.55	.56	.49	.56	.00	**−.07****	**−.07****
	(.50)	(.02)	(.03)	(.02)	(.02)	(.03)	(.03)
Quantity of males over 20 years old in household	1.30	1.30	1.27	1.31	.01	−.03	−.04
	(.73)	(.02)	(.04)	(.03)	(.03)	(.05)	(.05)
Quantity of females over 20 years old in household	1.35	1.35	1.29	1.37	.02	−.06	−.08
	(.74)	(.02)	(.04)	(.03)	(.04)	(.05)	(.05)
Quantity of males under 20 years old in household	1.52	1.47	1.52	1.57	.10	.05	−.05
	(1.39)	(.05)	(.08)	(.05)	(.07)	(.09)	(.09)

(Continues)

TABLE 2 (Continued)

Variable	All	Control	group-PVS	tricot-PVS	Delta tricot-PVS, control	Delta group-PVS, control	Delta tricot-PVS, group-PVS
Quantity of females under 20 years old in household	1.32	1.25	1.38	1.40	**.15*** **	**.13***	−.02
	(1.28)	(.04)	(.08)	(.05)	(.06)	(.08)	(.09)
Proportion of people with severe risk of lack access to food	.38	.35	.40	.42	**.07*** **	**.05***	−.02
	(.49)	(.02)	(.03)	(.02)	(.02)	(.03)	(.03)
First harvest of 2014 (kg)	147.61	154.08	129.29	148.07	−6.01	−24.79	−18.78
	(226.77)	(11.51)	(12.45)	(15.8)	(19.22)	(20.30)	(25.35)
Second harvest of 2014 (kg)	362.82	373.82	312.04	368.34	−5.48	**−61.78***	−56.30
	(502.71)	(18.13)	(29.68)	(21.9)	(28.27)	(36.98)	(39.42)
First planted area in 2014 (ha)	.30	.30	.32	.28	−.02	.02	.04
	(.30)	(.01)	(.03)	(.02)	(.02)	(.03)	(.03)
Second planted area in 2014 (ha)	.51	.51	.48	.52	.01	−.03	−.04
	(.48)	(.02)	(.03)	(.02)	(.03)	(.04)	(.04)
Proportion of people with bean crop	.89	.89	.92	.88	−.01	.03	.04
	(.31)	(.01)	(.02)	(.01)	(.01)	(.02)	(.02)
Proportion of people that fertilize the beans	.12	.11	.13	.12	.01	.02	.01
	(.32)	(.01)	(.02)	(.01)	(.01)	(.02)	(.02)
Proportion of land ownership	.75	.77	.75	.72	**−.05*** **	−.02	.03
	(.43)	(.01)	(.02)	(.02)	(.02)	(.03)	(.03)
Observations	1978	845	394	739	–	–	–

Bold values indicate significance. Significance level: P-value *< .01 (***); < .05(**); < .10 (*). In parentheses, standard errors.*

assigned into the tricot-PVS treatment. They did not have the chance to receive the seeds, so we considered them as if they had not been treated (project-induced attrition). Some of the potential participants were contacted, but the seed was not delivered after a few attempts. We considered these as if they had left the study (self-induced attrition). Project-induced attrition reduced the number of study participants from 1978 to 1879, divided as follows: 845 control farmers (521 control-in-control and 324 control—in—treatment), 331 group-PVS participants, and 703 tricot-PVS participants. The balance among participants' characteristics remains unchanged (Appendix, Table A4). Survey attrition (i.e., farmers survey at baseline but not at endline because they were not found, moved out or deceased) was 5%: 121 farmers dropped out from the first to the second round of interviews.

The self-induced attrition rate at the end of the participatory approaches is of particular interest. If a beneficiary did not complete all the participatory steps, from the kick-off training up to the traits evaluation, they were listed as a participant affected by self-induced attrition. Self-induced attrition further decreases the number of study participants to 1724, divided as follows: 845 control farmers (487 control-in-control village and 358 control—in—treatment villages), 268 group-PVS participants and 611 tricot-PVS participants.

4 | ESTIMATION STRATEGY

A simple way to estimate the treatment effects on on-farm varietal diversification and food security would be using the following model:

$$y_i = \alpha + \beta_1 T_i + \sum \gamma C_i^j + \varepsilon_i \qquad (2)$$

where y_i is the outcome variable for farmer *i* (the value of bean variety count index, the variety richness index, and the Household Hunger Score); T_i is the category treatment variable; C_i^j is the set of control variables *j* attached to each farmer *i;* and β_1 is the estimated treatment effect. ϵ_i is a random error clustered at village level.

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However, the model in Equation (2) has several drawbacks, as it does not account for unobserved heterogeneity and attrition. Therefore, following closely Ogutu et al. (2020), we estimate difference-in-difference models using baseline and endline data. Firstly, we clearly define the treatment variables. We identify treatment simply as being a member of a farmer group that was randomly assigned to a treatment arm. This is the intent-to-treat (ITT) effect. The ITT effect does not account for possible non-compliance, which is better accounted for by the treatment-on-the-treated (TOT) effect. As attrition is non-zero in our study, we calculate both the ITT effect and TOT effect (in line with Banerjee et al., 2016; Ogutu et al., 2020).

We estimate the ITT effect using the following difference-in-difference specification:

$$y_{it} = \alpha + \beta_1 Post_t + \beta_2 T_j + \beta_3 Post_t * T_j + \sum \gamma C_i^j + \epsilon_i \quad (3)$$

where y_{it} is the value of bean variety count index; the variety richness index, and the Household Hunger Score in year t (at endline); $Post_t$ is a year dummy that takes value 1 for the endline data (in 2018), and T_j is a dummy variable that takes value of 1 if a farmer is treated, and zero otherwise. For each treatment, we estimate a separate model compared to the control groups (control-in-control and control-in-treatment villages). Therefore, at each time we only include the observations from the respective treatment group and the control. As for the equations above, C_i^j is the set of control variables j attached to each farmer i.

The parameter of particular interest in Equation (3) is β_3, which is the difference-in-difference estimator of the ITT effect. Under the assumption of parallel trends, the difference-in-difference estimator overcomes possible selection bias from the absence of perfect balance in the baseline covariates (Greene, 2012).

In a complementary manner, we estimate the TOT effect by using actual program attendance as treatment variables. Unfortunately, data do not allow us to discretize for different degrees of attendance: therefore, we are able to calculate only a basic TOT effect, given by a dummy variable *Attendance* that takes a value of 1 if the beneficiary attended all the assigned steps of the group-PVS or tricot-PVS approach, and 0 otherwise.

To calculate the TOT effect, we cannot ignore the fact that attendance is endogenous to the households. To avoid the endogeneity bias, we utilize an instrumental variable estimate, relying on the random assignment to a treatment group as a valid instrument. Once again, this procedure is validated by the work of Ogutu et al. (2020). Using the randomization status as an instrument is common in the analysis of RCT experiments (Carter et al., 2013). The instrument is considered valid if the following conditions apply: the offer to participate in the treatment is (i) random; (ii) highly correlated with actual attendance in the participatory approaches, and (iii) not correlated with the outcome variables, except through actual attendance of the participatory approaches. The first condition is easily met: by design, households were allocated randomly to each treatment. The offer to participate in the treatment is also highly correlated with the actual program attendance, as demonstrated by the first stage results (Table 5). The third assumption is difficult to prove, as the presence of spillover effects might hinder the effectiveness of this condition (Ogutu et al., 2020). For this reason, we calculate effects of the treatments comparing them to control farmers in control villages and control farmers in treated villages. Furthermore, we interpret TOT effects cautiously.

We estimate the TOT effects using the following instrumental variable difference-in-difference specification:

$$y_{it} = \alpha + \beta_1 Post_t + \beta_2 T_j + \beta_3 Post_t * T_j + \sum \gamma C_i^j + \epsilon_i \quad (4)$$

with

$$T_j = \alpha + z_j + \upsilon$$

where y_{it} is the value of bean variety count index, the variety richness index, and the Household Hunger Score in year t (at endline), $Post_t$ is a year dummy that takes value 1 for the endline data (in 2018), T_j is treatment obtained from the first—stage regression with the instrument z. As for the equations above, C_i^j is the set of control variables j attached to each farmer i. To compute the instrumental variable difference-in-difference specification, we apply the two-stage least squares estimator, which produces estimates with a robust causal interpretation also with non-continuous treatment variables (Angrist & Pischke, 2009). Finally, to further control for samples selection problems and attrition bias, we use inverse probability weighting in the instrumental variable difference-in-difference specification.

4.1 | Estimates of the mechanisms and attrition

To rationalize mechanisms behind changes in on-farm varietal diversification and food security, we analyze how adoption, yield and quality of seeds delivered vary between tricot-PVS and group-PVS beneficiaries. Therefore, we estimate three multinomial logit models, which take the following form:

$$y_i = \alpha + \beta_1 T_i + \sum \gamma C_i^j + \epsilon_i \quad (5)$$

where y_i is the outcome variable for farmer i (adoption, the yield, or the ability of the approach to multiply and deliver seeds); T_i is the category treatment variable; C_i^j is the set of control variables j attached to each farmer i, and ϵ_i is a random error clustered at village level. β_1 is the coefficient of interest and γ^j is the coefficient attached to each control j.

Finally, we constructed a binomial regression exercise to observe self-induced attrition rates among participants. As the two approaches differ for degree of engagement, we are interested in exploring whether this difference relate with changes in varietal diversification and food security observed among treated participants. The logistic model — iterated only among those households involved in a treatment — encompasses an *attrition*-dependent variable, which takes value 1 when the household head took part in the participatory program but did not return the evaluation results. The model includes observations from the baseline survey:

$$Attrition_i = \alpha + \beta T_i + \sum \gamma C_i^j + \epsilon_i \qquad (6)$$

where $Attrition_i$ is a dummy variable that indicates if the beneficiary i dropped out of the program; T_i is a dummy variable that takes value 1 for the group-PVS approach and 0 for the tricot-PVS approach; C_i^j is a set of control variables j attached to each farmer i; β is the coefficient for the estimated attrition probability, and ϵ_i is a random error clustered at village level. The set of control variables is inserted in order to mitigate some imbalances present among participants and drop-out farmers (Appendix, Table A5). Farmers completing the participatory approaches tend to (a) have a larger household size, (b) be female-headed, (c) have less land devoted to bean cultivation, and (d) consequently buy more beans from the market. These biases are common in participatory studies that attempt to engage vulnerable farmers over longer periods of time (Langyintuo & Setimela, 2009).

Estimates from Equations (5) and (6) are indicative of how these three mechanisms vary according to the participants' treatment, without expressing any causal relation. They are nonetheless useful to discuss mechanisms behind the main findings. All analysis are performed in R (R Core Team 2020).

5 | RESULTS

5.1 | Estimation of the ITT effects

5.1.1 | ITT effects with respect to control farmers in control villages

Farmers participating in the group-PVS approach have a bean variety count index that is not statistically different with respect to control farmers in control villages (an average of 1.35 for group-PVS participants with respect to 1.25 for control-in-control farmers) (Table 3). Farmers involved in the tricot-PVS approach instead have a bean variety count that is 15% higher and significant (1.37 with respect to 1.25). On average, on-farm varietal diversification in terms of variety richness is also higher for group-PVS (5.36) and tricot-PVS (4.44) participants with respect to control-in-control farmers (3.46). The model estimation suggest that farmers engaged in the group-PVS approach have a variety richness index that is 55% higher than control farmers; involvement in the tricot-PVS approach also results in higher levels of variety richness index (61%), but neither of the two effects is statistically significant. Finally, group-PVS involvement reduces the likelihood of having a higher household hunger score with respect to farmers involved in the control groups, but the effect is not significant. On the contrary, tricot-PVS involvement seems to increase the household hunger score, with $P < .1$. On average, the household hunger score is 1.21 for group-PVS farmers, 1.26 for control-in-control farmers and 1.27 for tricot-PVS farmers.

5.1.2 | ITT effects with respect to control farmers in treated villages

Comparing effects on treatment farmers and control farmers in treatment villages helps understand the presence of spillover effects. On average, group-PVS farmers have a varietal count index of 1.35 and a variety richness index of 5.36, while control farmers in treatment villages register a count index of 1.22 and a variety richness index of 3.81. However, the model shows that for the bean count outcome, the effect is not significant. Similarly, group-PVS farmers have a variety richness index which is higher but not significant with respect to non-treated co-villagers. The household hunger score shows instead significant differences: group-PVS participants have a 109% lower chance of having higher levels of food insecurity (1.21 on average with respect to 1.35 for control-in-treatment households). Tricot-PVS participants have a lower chance of experiencing food insecurity in a severe manner (1.27 with respect to 1.35), but the effect is never significant. Conversely, bean variety count shows significant differences between tricot-PVS farmers and non-treated co-villagers: participants persist in showing a higher bean variety count of 11% (on average, 1.37 with respect to 1.22).

We show estimates with and without baseline controls included: ITT effects in both cases are very similar in magnitude and significance.

5.2 | Estimation of the TOT effects

The treatment-on-the-treated estimations generate results that partially resemble the ITT effects (Table 4). More

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TABLE 3 Effects of diverse participatory approaches distinguishing control-in control farmers from control-in-treatment farmers, ITT estimates.

	Dependent variable					
	Bean variety count index		**Variety richness index**		**HHS index**	
T1 – C_C						
Post × T1	.02	.04	.60	.55	−.33	−.46
	(.06)	(.06)	(.54)	(.52)	(.39)	(.43)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	$R^2 = .01$	$R^2 = .03$	$R^2 = .03$	$R^2 = .09$	AIC: 1165	AIC: 1086
Observations	1549	1549	1549	1549	1549	1549
T1 – C_T						
Post × T1	.02	.01	.38	.39	**−1.05***	**−1.09***
	(.07)	(.07)	(.62)	(.60)	(.41)	(.45)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	$R^2 = .01$	$R^2 = .03$	$R^2 = .01$	$R^2 = .10$	AIC: 968	AIC: 897
Observations	1261	1261	1261	1261	1261	1261
T2 – C_C						
Post × T2	**.14**	**.15**	.56	.61	**.68**	**.62***
	(.05)	(.05)	(.52)	(.51)	(.30)	(.33)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	$R^2 = .01$	$R^2 = .02$	$R^2 = .02$	$R^2 = .07$	AIC: 1688	AIC: 1477
Observations	2094	2094	2094	2094	2094	2094
T2 – C_T						
Post × T2	**.14**	**.11***	.34	.39	−.03	−.11
	(.06)	(.06)	(.61)	(.60)	(.31)	(.36)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	$R^2 = .01$	$R^2 = .01$	$R^2 = .01$	$R^2 = .07$	AIC: 2523	AIC: 1277
Observations	1806	1806	1806	1806	1482	1806

Note: coefficient estimates are shown with robust standard errors clustered at village level. Post is a dummy variable that takes the value of 1 for follow-up observations (at endline, after treatment) and zero for value at baseline. T1 is the group-PVS approach, T2 is the tricot-PVS approach, C_C are control farmers in control villages while C_T are control farmers in treatment villages. For brevity, not all variables are shown. Baseline controls include presence of off-farm income, household size, respondent's gender, ethnic group and age, total area under bean cultivation, total bean production, and dummy for the fact that the person in charge of harvesting the beans is a female.

Bold values indicate significance. Significance level: *P*-value < .01 (***); < .05(**); < .10 (*). Estimation strategy: difference-in-difference with inverse probability weighting model.

specifically, group-PVS participants show a considerably higher variety richness index (141%) with respect to control farmers in control villages. In parallel, tricot-PVS participants show a higher bean variety count index (11%) with respect to control farmers in control villages. TOT effects on the household hunger scores highlight no significant differences among treated farmers and control farmers in control villages. This is confirmed by the average absolute values of the outcome, which varies slightly (1.18 or group-PVS, 1.26 for tricot-PVS and 1.26 for control farmers in control villages).

Spillover effects appear to mitigate differences in terms of tricot-PVS performance, as coefficient estimates are not-significant for all the three outcome variables when treated farmers and control farmers in treated villages are considered. TOT effects on the variety richness index are significantly different only for group-PVS farmers, who show an index that is 135% higher compared to control-in-treatment farmers (but only in the absence of additional controls). Once again, interesting results emerge when considering the household hunger score. Despite the presence of potential spillover mechanisms, group-PVS farmers have a 14% lower chance of experiencing higher hunger score levels with respect to non-treated co-villagers.

Results of the first stage confirm that the offer to participate in the treatment is also highly correlated with the actual approach attendance.

Tests show that the instrument is not weak in none of the specifications considered (weak instruments test with $P < .01$). The null hypothesis of Wu-Hausman test cannot

TABLE 4 Effects of diverse participatory approaches distinguishing control-in control farmers from control-in-treatment farmers, TOT estimates.

	Dependent variable					
	Bean variety count index		**Variety richness index**		**HHS index**	
T1 – C_C						
First stage						
.69*** (R^2 = .56)						
Post × T1	.11	.06	**1.39****	**1.41****	−.05	−.05
	(.08)	(.08)	(.66)	(.66)	(.04)	(.05)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	R^2 = .01	R^2 = .03	R^2 = .03	R^2 = .02	R^2 = .05	R^2 = .05
Weak instruments	1491***	1061***	1311***	1310***	1668***	1307***
Wu-Hausman	.74	.51	4.24**	3.93**	2.89*	1.92
Observations	1549	1549	1549	1549	1549	1549
T1 – C_T						
First stage						
.69*** (R^2 = .51)						
Post × T1	.06	.03	**1.35***	.98	**−.13*****	**−.14****
	(.09)	(.09)	(.79)	(.75)	(.05)	(.05)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	R^2 = .01	R^2 = .03	R^2 = .01	R^2 = .09	R^2 = .02	R^2 = .02
Weak instruments	1048***	925***	924***	924***	1196***	925***
Wu-Hausman	.75	.23	3.94**	1.59	2.80*	2.86*
Observations	1261	1261	1261	1261	1261	1261
T2 – C_C						
First stage						
.83*** (R^2 = .67)						
Post × T2	.07	**.12***	.12	.21	.03	.03
	(.06)	(.06)	(.60)	(.58)	(.03)	(.04)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	R^2 = .01	R^2 = .02	R^2 = .01	R^2 = .07	R^2 = .01	R^2 = .03
Weak instruments	2788***	2463***	2350***	2345***	3058***	2463***
Wu-Hausman	3.84*	1.16	2.15	2.02	1.84	1.91
Observations	2094	2094	2094	2094	2094	2094
T2 – C_T						
First stage						
.83*** (R^2 = .61)						
Post × T2	.05	.07	−.21	−.18	−.04	−.04
	(.07)	(.07)	(.73)	(.71)	(.04)	(.04)
Baseline controls	No	Yes	No	Yes	No	Yes
Model fit metric	R^2 = .01	R^2 = .01	R^2 = .01	R^2 = .06	R^2 = .01	R^2 = .01
Weak instruments	1954***	1714***	1651***	1629***	2190***	1714***
Wu-Hausman	3.86**	1.2	2.01	2.27	1.79	2.26
Observations	1806	1806	1806	1806	1482	1806

Note: coefficient estimates are shown with robust standard errors clustered at village level. Post is a dummy variable that takes the value of 1 for follow-up observations (at endline, after treatment) and zero for value at baseline. T1 is the group-PVS approach, T2 is the tricot-PVS approach, C_C are control farmers in control villages while C_T are control farmers in treatment villages. For brevity, not all variables are shown. Baseline controls include presence of off-farm income, household size, respondent's gender, ethnic group and age, total area under bean cultivation, total bean production, and dummy for the fact that the person in charge of harvesting the beans is a female.

Significance level: *P*-value < .01 (***); < .05(**); < .10 (*). Estimation strategy: instrumental variable difference-in-difference with inverse probability weighting model.

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TABLE 5 Estimates on mechanisms and attrition.

	Dependent variable						
	Adoption		**Yield (qq/ha)**		**Seed production and delivery**		**Self—induced attrition rate**
	Multinomial logit		***OLS***		***Binomial logit***		***Binomial logit***
Treatment							
(Baseline: group-PVS)							
Tricot-PVS	**−4.01*** **	**−3.08*** **	**−295** **	**−212.7***	**−4.14** **	**−4***	
	(.62)	(.52)	(115)	(118)	(1.88)	(2.02)	
Baseline controls	No	Yes	No	Yes	No	Yes	
R^2	.01	.02	.17	.17	.02	.02	
Observations	1034	1034	1034	1034	1034	1034	
Treatment							
(Baseline: group-PVS)							
Tricot-PVS	−.0009	−.0003	−499	−561			
	(.0001)	(.0007)	(245)	(359)			
Delivery of preferred variety	.0004	.00005	**42.29***	52.23			
	(.0001)	(.0007)	(24.31)	(40.20)			
Baseline controls	No	Yes	No	Yes			
R^2	.002	.03	.25	.26			
Observations	1034	1034	1034	1034			
Treatment							
(Baseline: tricot-PVS)							
Group-PVS							**.67*** **
							(.26)
Baseline controls							Yes
R^2							AIC: 2489
Observations							1034

Note: coefficient estimates are shown with robust standard errors clustered at village level. For brevity, not all variables are shown. Baseline controls include presence of off-farm income, household size, respondent's gender, ethnic group and age, a dummy for the fact that the person in charge of harvesting the beans is a female, the variety count index at baseline, the household hunger score at baseline, the total amount of bean produced at baseline and the number of bean varieties known outside those proposed by the intervention.
Bold values indicate significance. Significance level: P-value *< .01 (***); < .05(**); < .10 (*)*. Observations are reduced as we are not considering control households.

be rejected, showing that the OLS and IV estimates are similar, and endogeneity may not have been a big problem in our dataset. For other cases, the null hypothesis of Wu-Hausman test can be rejected and the IV estimates are to be preferred.

5.3 | Estimation of the mechanisms and attrition

Descriptive estimates from Equation (5) are reported in Table 5. Findings help shed a light on the role of adoption, yield, and delivery of preferred variety in mediating effects between group-PVS and tricot-PVS attendance. As we are interested in estimates of participants only, we restrict the sample of this estimation to treated farmers.

Regarding adoption, tricot-PVS approach results in an adoption probability which is 4% lower with respect to the group-PVS approach. Similarly, the probability of receiving the preferred variety is 3% lower for the tricot-PVS treatment. group-PVS participants were more likely to receive the preferred variety, both in presence and absence of regression controls. Furthermore, group-PVS participants display positive effects on yield, while tricot-PVS farmers show a yield decrease both with and without additional baseline controls.

The ability of the approach to multiply and deliver seeds is not directly linked to the performance of the variety-testing approach, but rather to implementation. Therefore, we insert the ability of the approach to multiply and deliver seeds as a control in model of adoption and yield. Once we control for this factor, the participants in the two approaches show a negligible, non-significant difference in adoption levels. Instead, significant differences in yield remain.

Finally, we investigated whether the type of treatment generates different self-induced attrition rates (Equation 6). Group-PVS-treated farmers displayed a significantly higher attrition rate with respect to tricot-PVS farmers (Table 5). We found that when participants were selected for the group-PVS treatment, they had a 95% higher chance of experiencing self-induced attrition. In absolute terms, the number of targeted households who experienced attrition in group-PVS has been 126 out of 394 (32%), while for tricot-PVS attrition has been experienced by 128 out of 739 (17%).

6 | DISCUSSION

6.1 | Group-PVS and tricot-PVS lead to similar levels of on-farm varietal diversification

We hypothesized that the two participatory approaches would result in similar positive effects on varietal diversification, notwithstanding the fact that tricot-PVS exposes farmers to a more intensive observation of three varieties, while group-PVS exposes farmers to a less intensive observation of the whole set of varieties.

Our study confirms that farmers involved in the tricot-PVS or group-PVS approach do have a higher degree of bean varietal diversification compared to control farmers (Tables 3 and 4). We examined variety adoption rates to establish whether on-farm varietal diversification was potentially the result of adopting new varieties tested during the participatory approaches. Levels of adoption are positive and similar for the two approaches, after controlling for the site-specific ability of each approach to deliver the preferred variety (Table 5). Out of 394 group-PVS participants, 74 (18%) affirmed to continue harvesting the variety delivered after the intervention. Similar figures apply to tricot-PVS treated farmers, whose adoption rate is 20% after 3 years (146 adopters out of 739 participants). In absolute terms, adoption rates are in line with existing estimates of variety adoption (Thiele et al., 2021). Since the tested varieties were mostly new cultivars (Appendix, Table A1), an average of 20% for the adoption rate is considered promising.

It follows that, even though the two approaches differ widely in terms of relative investment and farmers' engagement, there is no evidence that they lead to different levels of on-farm varietal diversification.

6.2 | Effects on food security and the emergence of trade-off dynamics

For household food security, our hypothesis was less linear. Group-PVS participants are more exposed to agronomic training and exchanges with the technical staff and between farmers, so we expected this bean knowledge gain to lead to yield increases and higher food security for group-PVS participants. However, we also hypothesized that tricot-PVS participants might show higher levels of food security too, as variety testing decentralized at the farm level might result in higher seed retention, leading to higher adoption rates and food security.

Findings show group-PVS participants having a significant reduction in the household hunger score. This seems to confirm the first mechanism we hypothesized: higher food security might be driven by the difference in the number of meetings organized in each of the two programs. Tricot-PVS features an approach centered more on the individual farming household, with only two centralized meetings—an initial and a final meeting in which farmers and scientists discuss the tricot-PVS design and desired varietal characteristics. With an average of four to five participatory steps, group-PVS encompassed extensive agronomic trainings and discussions among farmers and experts. If these were to lead to higher levels of food security, we should observe higher group-PVS participants' sessions attendance to correlate positively with the household hunger score. We descriptively observe (Appendix, Table A6) that attending at least one meeting is correlated with higher levels of food security. The effect increases in magnitude and significance the more sessions participants decide to attend. Group-PVS treated farmers who attended three or more meetings have a 30% less likely to experience greater food insecurity. This mechanism appears to have a stronger effect on food security than bean variety adoption (Appendix, Table A6). Interestingly, lower household hunger scores for group-PVS farmers persist even among co-villagers: group-PVS farmers tend to perform better in terms of household hunger score, especially if compared to control farmers in treated villages (Table 5). This hints at the existence of a set of farmer-expert exchanges, which are intrinsic to the group-PVS approach and greatly benefit group-PVS participants. This result has implications beyond the breeding debate: farmer-expert exchanges and agronomic trainings should be encouraged and planned frequently in agricultural development activities as they do not simply enrich the knowledge of the parties involved, but they also contribute to better livelihoods of the beneficiaries.

An important consequence of engaging farmers with technical staff more frequently is the time commitment this requires to farmers, who are less accustomed to the iterative nature of the research process, and whose attendance is only rarely compensated. Results on attrition seem to suggest that group-PVS farmers have a 95% higher chance of experiencing self-induced attrition. This is consistent with previous findings, which show how group-PVS approaches are expensive in terms of time and resources and result in a high rate of self-induced attrition (Misiko, 2013). Reasons for attrition might be multiple. In our sample, farmers report not attending the entire group-PVS approach mainly because (in decreasing order of importance): (i) they could not attend the meeting in which the approach was presented, (ii) they had no land on which to plant the beans afterwards, (iii), they had recent conflicts with a neighbor of a group leader, or (iv) they had a no time to attend.

Broadly speaking, our results point towards the emergence of a trade-off. On the one hand, the two approaches have comparable effects on varietal diversification and adoption performance. Group-PVS participants also show higher levels of food security. However, the numerous steps, likely leading to higher food security performances, are the very same reason for which group-PVS approaches are expensive in terms of time and resources and result in a higher rate of self-induced attrition (Misiko, 2013).

6.3 | Implications for participatory varietal selection

GROUP-PVS showed higher direct benefits to participants. Variety adoption levels were similar but increases in yield and food security that followed from participation in the sessions were higher than for tricot-PVS participants. PVS exercises are often implemented by extension services and are therefore frequently expected to have the double purpose of (i) generating insights in variety suitability and (ii) to have direct effects on farming practice. Its contribution to both purposes could be interpreted as a strength of the group-PVS approach. However, the tricot-PVS approach showed attrition rates that were lower than group-PVS and comparable variety adoption rates. The lower attrition rates imply higher external validity of the information derived from the experiment (De Sousa et al., 2021). That more households are likely to drop out of the experiment in the group-PVS approach does not only limit their direct benefits from participating in the trial. It can also lead to a bias in the resulting variety recommendations. Group-PVS did lead to higher direct benefits, however, and these are highly correlated with the interactions between technical staff and farmers.

This signals that the optimum might be found if each of the approaches is used for their appropriate goal. Tricot-PVS should be used for on-farm testing and a group-based agronomy training could be delivered separately, for example, to farmers who have gone through one round of tricot-PVS. Such a hybrid approach would benefit from the lower attrition rate and the expected higher data value of tricot-PVS, but also benefit farmers in providing the benefits of improved agronomy, which can be achieved through a group-based training approach.

7 | CONCLUSION

The past decades have witnessed a gradual shift in the design and conceptualization of development projects and extension services, from a top-down implementation to active community involvement in problem identification and interventions' planning (Dirorimwe, 1998). While farmers' engagement has proven to be effective in enhancing local empowerment and sustainability (van de Gevel et al., 2020), a research gap persists on whether different methodologies of farmers' inclusion affect participants' on-farm varietal diversification and food security in the medium-term. Our study revealed that farmers involved in the group-PVS, and tricot-PVS approach have a higher degree of on-farm varietal diversification than control farmers. Furthermore, group-PVS increases the odds of experiencing lower levels of household food insecurity after 3 years from the start of the engagement program, compared to control farmers. This appears to be strongly related to the interaction between staff and farmers. Tricot-PVS presents lower self-induced attrition rates among participants and leads to similar levels of variety adoption.

These findings suggest that national programs can benefit from the cost-effective, equitable, externally valid, and scalable nature of tricot-PVS for the goal of informing breeding programs. As suggested by the literature on farmers' stepwise technology adoption process (Doss, 2006), it is reasonable to separate seed innovation and crop management components and treat them in an "additive" way. Investors and policymakers should target participatory variety selection for improving knowledge about the local suitability of varieties and increasing the overall positive impact of the investments in plant breeding in terms of effectiveness and inclusiveness. Delivering other possible direct benefits to individual participants is equally important and it might be achieved by providing a group-based agronomy training, which can be delivered separately. Separate approaches for knowledge generation through participatory variety selection, using decentralized methods such as tricot-PVS, can achieve larger and more equitable impact with the same resources.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's website: Appendix

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SUPPORTING INFORMATION

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APPENDIX

Group-PVS and tricot-PVS protocol

TABLE A1 Protocol for the establishment of group-PVS groups.

Meeting	Day	Main activities
1	10 days before planting	Invite families to constitute the PVS group (at least two members of each family). Explain the aims of the PVS group.
2	Planting date	Establishment of experimental plots; Explanation on the variety assessments
3	7 days after planting	Assessment of leaf development and Vigor; discussion about the most vigorous varieties
4	35 days after planting	Assessment of varieties (architecture, resistance to pests and diseases); discussion about the best varieties during vegetative stage
5	On harvesting day (~ 60 days after planting)	Assessment of yield, market value and taste; discussion about overall preference
6	70 after planting	Present final results. Distribute seeds that were preferred by farmers

TABLE A2 Protocol for the evaluation of on-farm trials under the tricot-PVS approach.

Data collection moment	Day	Main activities
1	30 days after planting	Evaluation of leaf development (vigor)
2	45 days after planting	Evaluation of architecture, resistance to pests and resistance to diseases
3	On harvesting day (~60 days after planting)	Evaluation of yield, market value and taste
4	After harvesting	Evaluation of overall preference, and Comparison between each of the three tricot varieties against the local variety (better or worse).

List of bean varieties included in the group-PVS and tricot-PVS approaches

TABLE A3 List of bean varieties proposed in the group-PVS and tricot-PVS approaches with date of release.

ID-EPM trial name	Varietal name	Year of release	Country/Origin
MHN 322–49	ECO Negro	2018	Nicaragua
ICTA Peten ML	ICTA Peten ML	2011	Guatemala
MEN 2201–64	Lenca Precoz	2016	Honduras
ICTA Ligero	ICTA Ligero	1992	Guatemala
SEQ 342–89	N/A	Not released	Bean Research Program from Zamorano University
Azabache 40	Azabache 40	2016	Honduras
ICTA Vaina Roja	ICTA Vaina Roja	Not released	Guatemala
SEQ 342–87 ML	Breeding line	Not released	Bean Research Program from Zamorano University
ICTA Sayaxche ML	ICTA Sayaxche ML	2011	Guatemala
ICTAZAM ML	ICTAZAM ML	2012	Guatemala
Seda	Landrace	N/A	Honduras
RS 907–28	Breeding line	Not released	Bean Research Program from Zamorano University
BRT 103–182	Breeding line	Not released	Bean Research Program from Zamorano University
ALS 0532–6	Tolupan Rojo	2019	Honduras
SRS2-36-34	Breeding line	Not released	Bean Research Program from Zamorano University
RS 909–35	Breeding line	Not released	Bean Research Program from Zamorano University
SJC 730–79	Rojo Chortí	2019	Honduras
RS 336-28	Breeding line	Not released	Bean Research Program from Zamorano University
Amadeus 77	Amadeus 77	2003	Honduras

Tricot-PVS protocol for illiterate participants

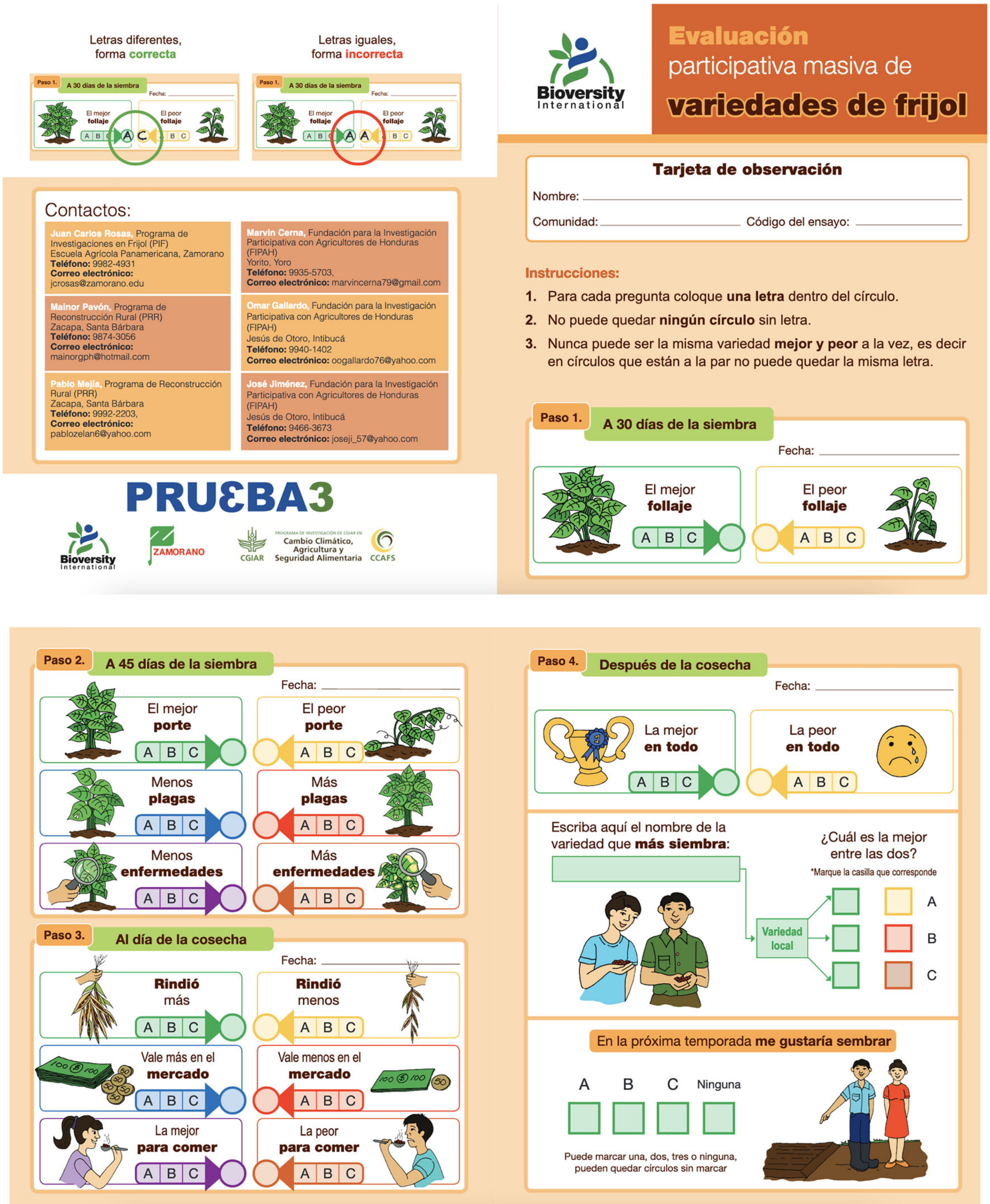

FIGURE A1 Illustrations for evaluation of tricot-PVS varieties by illiterate participants.

Household Hunger Score module in the survey

The following module was inserted in the survey (both at baseline and endline) to calculate the Household Hunger Score indicator:

1. In the past 4 weeks, was there ever no food to eat of any kind in your house because of lack of resources to get food? (Yes/No)

a. If yes, how often did this happen, in the past 4 weeks? (rarely/sometimes/often)

2. In the past 4 weeks, did you or any household member go to sleep at night hungry because there was not enough food?

b. If yes, how often did this happen, in the past 4 weeks? (rarely/sometimes/often)

3. In the past 4 weeks, did you or any of your household member go a whole day and night without eating anything at all because there was not enough food?

c. If yes, how often did this happen, in the past 4 weeks? (rarely/sometimes/often)

The 4 weeks lagged period at the beginning of each question allows the respondents to make a reasoned assessment, without incurring into measurement bias dictated by a longer recall period.

Self-induced attrition rate among study participants

TABLE A4 Summary statistics among treatment groups at baseline, after dropping participants affected by project-induced attrition.

Variable	All	Control	group-PVS	Delta group-PVS, control	tricot-PVS	Delta tricot-PVS, control	Delta tricot-PVS, group-PVS
Annual sales (kg)	32.94	33.10	24.44	−8.66	44.31	11.21	−19.87
	(223.4)	(7.21)	(11.23)	(14.99)	(10.8)	(12.76)	(18.21)
Land for productive activities (ha)	.94	.92	.83	−.11	.97	.03	**−.12***
	(1.11)	(.04)	(.02)	(.07)	(.04)	(.02)	(.07)
Annual purchase(kg)	21.71	19.62	24.00	4.38	23.21	**3.75***	.49
	(49.84)	(1.42)	(2.9)	(3.08)	(1.92)	(2.37)	(3.60)
Proportion of households with only women	.11	.13	.11	−.02	.12	−.01	−.01
	(.33)	(.01)	(.02)	(.02)	(.01)	(.02)	(.02)
Proportion of households with a couple	.82	.81	.82	.01	.84	**.03***	−.02
	(.38)	(.01)	(.02)	(.03)	(.01)	(.02)	(.02)
Age of the head of household	34.50	43.89	43.76	−1.15	44.29	−.62	−.53
	(13.63)	(.38)	(.87)	(.99)	(.52)	(.71)	(.99)
Proportion of women interviewed	.55	.52	.60	**.05*****	.46	**.06*****	.14
	(.50)	(.02)	(.03)	(.03)	(.02)	(.02)	(.03)
Proportion of people with debts	.20	.25	.16	−.09	.15	**−.10***	.01
	(.40)	(.04)	(.06)	(.07)	(.04)	(.05)	(.07)
Number of people in households	5.49	5.36	5.45	.11	5.66	**.29*****	−.18
	(2.42)	(.08)	(.14)	(.16)	(.09)	(.11)	(.16)
Weekly consumption of beans (kg)	2.87	2.75	2.83	.08	3.05	**.30*****	**−.22***
	(1.77)	(.05)	(.10)	(.11)	(.07)	(.08)	(.12)
Proportion of households with children under 13 years old	.78	.74	.78	**.05***	.81	**.02*****	−.02
	(.42)	(.01)	(.02)	(.03)	(.01)	(.02)	(.03)
Proportion of people with complete primary school	.21	.22	.20	−.02	.18	−.03	.01
	(.40)	(.01)	(.02)	(.03)	(.01)	(.02)	(.03)
Proportion of people able to read and write	.55	.56	.49	**−.06****	.56	.00	**−.04****
	(.50)	(.02)	(.03)	(.03)	(.02)	(.02)	(.03)

(Continues)

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TABLE A4 (Continued)

Variable	All	Control	group-PVS	Delta group-PVS, control	tricot-PVS	Delta tricot-PVS, control	Delta tricot-PVS, group-PVS
Quantity of males over 20 years old in household	1.30	1.30	1.27	−.03	1.31	.01	−.04
	(.73)	(.02)	(.04)	(.05)	(.03)	(.03)	(.05)
Quantity of females over 20 years old in household	1.35	1.35	1.29	−.06	1.37	.02	−.08
	(.74)	(.02)	(.04)	(.05)	(.03)	(.04)	(.05)
Quantity of males under 20 years old in household	1.52	1.47	1.52	.05	1.57	.10	−.05
	(1.39)	(.05)	(.08)	(.09)	(.05)	(.07)	(.09)
Quantity of females under 20 years old in household	1.32	1.25	1.38	**.12***	1.40	**.13*****	−.02
	(1.28)	(.04)	(.08)	(.08)	(.05)	(.06)	(.09)
Proportion of people with severe risk to lack of food access	.38	.35	.40	**.02***	.42	**.07*****	−.02
	(.49)	(.02)	(.03)	(.03)	(.02)	(.02)	(.03)
First harvest of 2014 (kg)	147.61	154.08	129.29	−24.79	148.07	−6.01	−18.78
	(226.77)	(11.51)	(12.45)	(20.30)	(15.8)	(19.22)	(25.35)
Second harvest of 2014 (kg)	362.82	373.82	312.04	**−61.72***	368.34	−5.48	−56.30
	(502.71)	(18.13)	(29.68)	(36.98)	(21.9)	(28.27)	(39.42)
First planted area in 2014 (ha)	.30	.30	.32	.02	.28	−.02	.04
	(.30)	(.01)	(.03)	(.03)	(.02)	(.02)	(.03)
Second planted area in 2014 (ha)	.51	.51	.48	−.03	.52	.01	−.04
	(.48)	(.02)	(.03)	(.04)	(.02)	(.03)	(.04)
Proportion of people with bean crop	.89	.89	.92	.03	.88	−.01	.04
	(.31)	(.01)	(.02)	(.02)	(.01)	(.01)	(.02)
Proportion of people that fertilize the beans	.12	.11	.13	.03	.12	.01	.01
	(.32)	(.01)	(.02)	(.02)	(.01)	(.01)	(.02)
Proportion of land ownership	.75	.77	.75	−.04	.72	**−.05*****	.03
	(.43)	(.01)	(.02)	(.03)	(.02)	(.02)	(.03)
Observations	1879	845	331	–	703	–	–

Significance level: *P*-value < .01 (***); < .05(**); < .10 (*). In parenthesis, standard deviations.

TABLE A5 Summary statistics among participants and self-induced attrition rate farmers at baseline.

Variable	Participants	Drop-out farmers	Delta participants, drop-out farmers
Land for productive activities (ha)	.94	.80	**.14****
	(.84)	(.12)	(.72)
Annual purchase(kg)	16.76	8.12	**8.64***
	(28.66)	(19.71)	(8.95)
Proportion of households with only women	.11	.09	−.02
	(.01)	(.02)	(.02)
Proportion of households with a couple	.76	.72	.04
	(.01)	(.02)	(.01)
Age of the head of household	52.63	52.39	−.24
	(66.17)	(65.07)	(1.1)
Proportion of women interviewed	.44	.59	**.15*****
	(.02)	(.03)	(.03)
Proportion of people with debts	.23	.14	−.09
	(.04)	(.06)	(.07)
Number of people in households	5.65	5.28	**.37****
	(2.46)	(2.22)	(.24)
Weekly	3.57	2.21	1.36
consumption of beans (kg)	(.13)	(.10)	(.03)
Proportion of households with children under 13 years old	.93	.83	.10
	(.01)	(.02)	(.01)
Proportion of people with complete primary school	.25	.19	.06
	(.01)	(.02)	(.03)
Proportion of people able to read and write	.55	.48	.08
	(.02)	(.03)	(.03)
Quantity of males over 20 years old in household	1.33	1.43	**−.10***
	(.78)	(.79)	(.01)
Quantity of females over 20 years old in household	1.37	1.42	−.05
	(.73)	(.76)	(.03)
Quantity of males under 20 years old in household	1.45	1.54	.09
	(.05)	(.08)	(.09)
Quantity of females under 20 years old in household	1.23	1.34	**.11***
	(.04)	(.08)	(.08)
Average value on the HFIAS Hunger Scale	9.14	6.39	**2.75*****
	(5.92)	(5.62)	(.32)
First harvest of 2014 (kg)	368.18	349.08	19.1
	(291.47)	(298.07)	(6.53)
Second harvest of 2014 (kg)	372.27	373.22	−.7
	(261.93)	(252.24)	(9)
First planted area in 2014 (ha)	.14	.14	.00
	(.28)	(.29)	(.01)
Second planted area in 2014 (ha)	.27	.66	**−.39****
	(.15)	(.26)	(.11)
Proportion of people with bean crop	.88	.91	.03
	(.01)	(.02)	(.02)
Proportion of people that fertilize the beans	.13	.13	.00
	(.01)	(.02)	(.02)
Proportion of land ownership	.76	.67	**.09*****
	(.43)	(.47)	(.04)
Observations	879	254	–

Significance level: *P*-value < .01 (***); < .05(**); < .10 (*). In parenthesis, standard deviations.

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Correlation between group-PVS participants' HHS and training attendance

In the exercise below, we relate the degree of group-PVS participants' food security with their degree of attendance in agronomic meetings, utilizing a multinomial ordinal logit. We calculate the degree of attendance by simply counting the number of meetings in which the group-PVS farmer results as present on the attendance sheets. We treat the variable as a factor, whose baseline level is 1 if the farmer attended one meeting.

TABLE A6 Coefficients for household hunger score among group-PVS treated, after controlling the number of agronomic trainings attended and adoption.

	Dependent variable	
	Household Hunger Score	
Number of agronomic meetings attended = 1	**−1.38****	**−1.24*****
	(.48)	(.34)
Number of agronomic meetings attended = 2	**−1.38***	**−1.66*****
	(.61)	(.52)
Number of agronomic meetings attended = 3+	**−1.20*****	**−1.20*****
	(.41)	(.31)
Adoption of variety tested during GROUP-PVS	–	**−.39***
		(.23)
Baseline controls	Yes	Yes
AIC	526	917

Note: coefficient estimates are shown with robust standard errors clustered at village level. We perform this exercise only among group-PVS treated farmers, so the sample of the regression is 345. For brevity, not all variables are shown for brevity. Baseline controls include presence of off-farm income, household size, respondent's gender, ethnic group and age, total area under bean cultivation, total bean production, and dummy for the fact that the person in charge of harvesting the beans is a female.

Significance level: *P*-value < .01 (***); < .05(**); < .10 (*). The model is a multinomial ordinal logit.

Costs comparisons between tricot-PVS and group-PVS

To compare the cost of the two approaches, we compute the unit cost per participant involved. Each sum is therefore converted from the local currency into dollars and subsequently divided by the number of participants in the program.

TABLE A7 Cost comparisons between group-PVS and tricot-PVS.

	Cost per farmer involved	
	Group-PVS ($/participant)	Tricot-PVS ($/participant)
Facilitators	33.30	16.39
Transport	2.22	
Calls	.27	1.33
Preparation inputs	15	
Seeds	4.62	6.08
Materials for training	1.67	2.34
Coordination and training	11.11	
Overheads	10.23	3.92
Total cost per participant	78.41	30.07
Total number of participants	394	739
Total cost of the approach	30,893.54$	22,221.73$