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Do Plant Clinics Improve Household Food Security? Evidence from Rwanda

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Abstract

One of the main drivers of food insecurity is pests, which are estimated to cause around 40% of crop losses worldwide. We examine the food security effects of plant clinics, a novel agricultural extension model that aims to reduce crop losses due to pests through the provision of demand-driven plant health diagnostic and advisory services to smallholder farmers. The study is based on survey data from maize-growing households in Rwanda, where 66 plant clinics have been established. Using switching regression and matching techniques as well as various food security metrics, including the food insecurity experience scale, we find evidence that participation in plant clinics is significantly associated with a reduction in household food insecurity. For instance, among the participating households, plant clinics contribute to a decrease in the period of food shortage by one month and a reduction in the severity of food insecurity by 22 percentage points. We also show that these effects are more pronounced for female-headed households. Overall, our findings suggest that plant clinics can play an important role in achieving the Sustainable Development Goal 2 of zero hunger.

Keywords: *Agricultural extension*; *dietary diversity*; *food security*; *impact assessment*; *plant clinics*; *Rwanda.*

JEL classifications: *O13, Q1, Q12, Q16.*

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1. Introduction

Through the Sustainable Development Goal (SDG) 2, the world has committed to ending hunger and achieving food security and improved nutrition by 2030. Yet, recent evidence points to increasing hunger and food insecurity in the world. The number of undernourished people has increased from 784 million in 2015 to 821 million people in 2018, and an estimated 22.8% of the population in sub-Saharan Africa (SSA) is facing chronic food deprivation (FAO *et al.*, 2019), suggesting that much more effort is needed to achieve this development goal.

While food insecurity is driven by multiple factors, including climate shocks, conflict and insecurity, economic and political instability, an important though often neglected contributory factor is crop loss from pests and diseases (Flood, 2010; Savary *et al.*, 2012; FSIN, 2018). Worldwide, around one-third of attainable crop production is lost annually to pests, with a large share of the losses occurring in developing countries (Oerke, 2006; OECD-FAO, 2012). For instance, it is claimed that the recent outbreak of the fall armyworm (FAW) pest in Africa has the potential to cause annual maize losses of up to 20.6 million metric tons per year in 12 SSA countries (Day *et al.*, 2017). Pratt *et al.* (2017) have also demonstrated that five major invasive pests are capable of causing a combined annual economic loss of US$0.9–1.1 billion to smallholder maize production in just six East African countries.

In an effort to address pest problems, a global plant health programme led by CABI, dubbed Plantwise, was initiated in 2011 with the aim of increasing food security and improving rural livelihoods by reducing crop losses. A key component of the Plantwise programme has been the establishment of plant clinics, where farmers who are experiencing plant health problems can take samples of their ailing crops to trained plant health extension officers (referred to as plant doctors) for free diagnosis and recommendations on how to manage the problem. In this article, we assess the impact of plant clinics on household food security. The study is based on survey data from 637 smallholder maize-producing households in Rwanda, where food insecurity remains a challenge for many farm households (WFP, 2018).

In many developing countries, farmers depend largely on public extension workers for agricultural advisory services, including plant health information. However, due to weak extension systems, the extension workers have limited contacts with farmers and often fail to provide services tailored to the individual needs of farmers (Anderson and Feder, 2007). In the absence of expert advice, farmers may rely on their own experience, or seek out information from their peers and profit-driven agro-input dealers (Bett *et al.*, 2018; Silvestri *et al.*, 2019), who may be poorly informed on how to deal with unfamiliar pest problems. The plant clinic extension approach is considered as a promising model for solving farmers' challenges in accessing demand-driven plant health diagnostic and advisory services. Besides helping to detect pest outbreaks, plant clinics provide one-on-one regular plant health services at easily accessible locations.

The plant clinic extension approach has expanded rapidly over the past decade, with currently about 4,500 plant clinics established in 34 countries across Africa, Asia and the Americas (CABI, 2020). This surge in popularity of the plant clinic approach has been accompanied by increased interest in evaluating its impacts, but most of the existing literature has focused on immediate farm-level outcomes, such as farmers' knowledge of pests, adoption of pest management strategies, and yields (e.g., Bentley *et al.*, 2011; Brubaker *et al.*, 2013; Bett *et al.*, 2018; AIR, 2018; Silvestri *et al.*, 2019).

An exception is Tambo *et al*. (2020), who went beyond farm-level outcomes to examine the poverty reduction effects of plant clinics.

We contribute to this literature by providing evidence on the role of plant clinics in achieving household food security, which is the ultimate goal of the plant clinic extension programme (CABI, 2020) and a key development outcome, as emphasised in the SDG 2. Additionally, we investigate the heterogeneous effects of plant clinic participation by looking at impacts across gender groups and poverty levels. We estimate the impact of plant clinics on a number of food security indicators, including the food insecurity experience scale (FIES). Among the indicators for tracking progress towards the achievement of SDG 2 is indicator 2.1.2: ‘prevalence of moderate or severe food insecurity in the population, based on the FIES’. By applying the FIES measure, this paper, to our knowledge, is the first to empirically investigate the contribution of agricultural extension to the achievement of one of the targets of the second SDG of ‘zero hunger’. Finally, we add to the few studies in the literature (e.g., Larsen and Lilleor, 2014; Pan *et al*., 2018; Tambo *et al*., 2020) that have looked at the development effects (rather than immediate impacts) of agricultural extension programmes [see Anderson and Feder (2007) and Pan *et al*. (2018) for reviews of extension achievements].

The rest of this paper is structured as follows. Section 2 describes the study context, the data used in the analyses and methodology, including the pathways by which plant clinics could improve food security, the estimation techniques and food security measures. The descriptive and empirical results are presented in Section 3, and the last section concludes by highlighting key findings and policy implications.

2. Context, Data and Methods

2.1. Plant clinic programme in Rwanda

The plant clinic extension approach was initiated in Rwanda in 2011 through collaboration between the Plantwise programme and the Rwanda Agriculture and Animal Resources Development Board (RAB), which is the national organisation responsible for the implementation of plant clinic activities in the country. Eight plant clinics were established at the inception of the programme. Currently, there are 66 active plant clinics operating across the country’s 30 districts and 5 provinces (CABI, 2020). These clinics are run by 350 plant doctors who have been trained by the Plantwise programme to diagnose crop problems and make science-based recommendations, following the principles of integrated pest management (IPM).

The plant clinics offer open services (free-of-charge) twice a month at easily accessible locations, such as markets, village centres and farmers’ meeting sites. The clinic sessions are advertised through multiple channels, including banners, farmer groups, extension agents and megaphones. The set-up for a clinic session includes two plant doctors, a banner, an umbrella, tables, chairs and basic pest diagnostic materials, such as hand lenses and reference books on pests. Any farmer can bring a sample of any ‘sick’ crop to the clinics, and a plant doctor will examine the sample, diagnose the problem and suggest appropriate management actions. To aid diagnoses and recommendations, the plant doctors have access to the Plantwise Knowledge Bank, which is an open-access online source of plant health information. The plant clinics do not provide free or subsidised farm inputs to the participating farmers.

Each clinic participant is issued a prescription form, which records basic information about the farmer (such as gender, location and contact details), crop brought to the clinic, symptoms of pest attack, diagnosis and recommendations. These data are subsequently transferred into the Plantwise Online Management System (POMS). The POMS data provide insight into the prevalence and spread of crop pests in the Plantwise programme countries. According to POMS data, during the 2017–2018 cropping seasons, the plant clinics in Rwanda attended to nearly 4,000 farmers' queries (63% and 37% from male and female farmers, respectively) related to maize, banana, cassava, tomato and potato. Maize constituted more than half (56%) of the queries, and fall armyworm (FAW) and maize stalk borer (MSB) were the most common plant health problems, comprising 93% of the queries on maize.

2.2. Data

This study is based on a survey of 637 smallholder maize-growing households (263 clinic users and 374 non-clinic users) in three provinces in Rwanda (Figure A1, Online Appendix). Prior to the survey, an analysis of POMS data revealed that the majority of Rwandan farmers who visited plant clinics with crop health problems sought advice related to maize, hence, the focus on maize-producing households. Given the spatial dispersion of farmers who visited plant clinics with maize-related pest problems, we used a three-stage sampling process to select the sample households.

First, based on the POMS data, we identified three (i.e., Northern, Southern and Western) of the five provinces in Rwanda where maize is an important crop and where there are increased incidences of maize pests, particularly FAW and MSB. We excluded Kigali province (which is largely urban) and Eastern province (which had very few farmers' queries on maize pests). Thus, our data are not nationally representative, but can be considered representative of the main maize farming systems with high severity levels of maize pests in Rwanda. Second, we selected 15, 13 and 6 sectors in Northern, Southern and Western provinces, making a total of 34 sectors across the three provinces.[1] The sectors were purposively selected based on plant clinic operations and high incidence of maize pests, as recorded in POMS. Third, within each sector, we randomly selected 5 to 10 maize-producing households from a list of farmers that had visited plant clinics during the 2017–2018 cropping seasons. Similarly, within each sector and in consultation with local agricultural extension officers, we randomly selected between 7 and 12 non-users of plant clinics from a list of maize producing households that had experienced similar maize pest problems during the 2017–2018 cropping seasons and shared similar contextual characteristics such as agro-ecological zone and crops grown with the clinic users. A mean comparison between clinic users and non-users on the main characteristics used in selecting the sample households is presented in Table A1 in the Online Appendix, which suggests substantial similarity.

The first section of the questionnaire included filter questions to ensure that the selected non-clinic users are maize farmers who experienced MSB or FAW attacks on their maize crops during the past cropping season and had never used plant clinic services. Furthermore, the POMS database was used to confirm that the selected clinic users had actually visited plant clinics to seek advice related to MSB or FAW and that

[1]A sector is a third tier of government administration in Rwanda (i.e., province, district and sector).

non-clinic users had never attended plant clinic sessions. Data were collected between May and June 2018 by trained enumerators using a structured, tablet-based questionnaire that contained modules on household demographic and socio-economic characteristics; maize production; adoption and knowledge of interventions for pest and disease management; sources of information about pests and diseases; proximity to institutional support services; and our food security indicators.

2.3. Conceptual and empirical framework

As noted earlier, the primary objective of this paper is to estimate the effect of plant clinics on household food security. This can be specified as:

$$y_i = \alpha_i + \beta x_i + \varphi P_i + \mu_i \qquad (1)$$

where y_i represents the indicator of household food security, which we present in the next subsection; x_i is a vector of explanatory variables, with the associated parameters β; P_i is a dummy variable equal to one if household i participates in plant clinics and zero otherwise; and μ_i is a random error term. We are particularly interested in the coefficient φ, which measures the effect of participating in plant clinics on household food security.

There are a number of likely mechanisms through which participating in plant clinics can affect household food security. First, plant clinics stimulate the uptake of crop protection technologies (Silvestri *et al.*, 2019), and this may reduce crop losses, increase production, and subsequently result in improved household food availability. Second, higher crop yields (due to reduced crop losses) could translate into increased income from crop sales that can be used to purchase food. Moreover, the income saved from household consumption of self-produced crops (as a result of higher yields) can be spent on other food not produced by the household. Third, plant doctors are trained to offer plant health advice to clinic users by following the tenets of IPM, which includes rotation and intercropping with non-host crops to prevent the build-up of pests. Using crop rotation and intercropping as a pest management strategy indirectly increases production diversity, and a number of studies (such as Jones *et al.*, 2014; Romeo *et al.*, 2016; Sibhatu and Qaim, 2018) have shown that farm production diversity contributes significantly to improved household dietary diversity. A final potential pathway is through female empowerment and intra-household resource allocation. In many developing countries, women play a key role in ensuring household food security, but tend to have limited access to agricultural extension services (Quisumbing *et al.*, 1996; Doss, 2001). By design, plant clinics provide services that are inclusive to all types of farmers, and female participation could influence household and intra-household food distribution, given the increasing evidence that income controlled by women has a positive effect on household food and nutrition security (Quisumbing *et al.*, 1996; Meinzen-Dick *et al.*, 2012).

Participation in plant clinics is not randomly assigned; hence, our treatment variable P is potentially endogenous to the outcome indicators y. Since it is possible that some unobservable characteristics, such as ability and motivation, might influence farmers' decision to participate in plant clinics and household food security simultaneously, failure to account for this may yield biased impact estimates. To address the endogeneity concern, we employ endogenous switching (ES) models, which are estimated using the full information maximum likelihood procedure (Lokshin and Sajaia, 2004; Lokshin and Sajaia, 2011; Läpple *et al.*, 2013; Shiferaw *et al.*, 2013). However, as a robustness check, we also use a selection-on-observables estimator (propensity score matching), which we present later.

In the ES framework, separate outcome (food security) equations are specified for plant clinic participants and non-participants, conditional on clinic participation decision:

$$P_i = \delta z_i + \varepsilon_i \tag{2a}$$

$$y_{1i} = \beta_1 x_i + \mu_{1i} \quad if P = 1 \tag{2b}$$

$$y_{2i} = \beta_2 x_i + \mu_{2i} \quad if P = 0 \tag{2c}$$

where y_{1i} and y_{2i} denote a vector of food security indicators for clinic participants and non-participants, respectively. β_1 and β_2 are parameters to be estimated for the participants and non-participants regimes, respectively, and z_i and x_i represent a set of explanatory variables that affect plant clinic participation and the food security indicators, respectively. The explanatory variables are motivated by literature on the determinants of food security as well as the impact of plant clinics or agricultural extension in Africa (e.g., Feleke *et al*., 2005; Larsen and Lilleor, 2014; Silvestri *et al*., 2019). The variables include household characteristics (e.g., age, gender and education of the household head, household size and dependency ratio); as well as financial capital and institutional-related factors (e.g., land and livestock holdings, durable asset index, access to credit, and proximity to markets and extension services). We also include household risk preference and province fixed effects, which capture province-specific heterogeneity such as density of plant clinics and intensity of pest problems. A detailed description of the explanatory variables is presented in Table 1.

While the variables that appear in the selection and outcome equations can be identical (i.e., $z_i = x_i$), a more robust identification requires an exclusion restriction; that is, at least one variable that influences plant clinic participation but does not have a direct effect on our outcomes of interest. Inspired by studies that employed distance to sources of information as an identifying instrument when assessing the impact of agricultural innovations on household food security in Africa (e.g., Shiferaw *et al*., 2013; Tambo and Wünscher, 2017), we use the distance between a household's residence and the nearest plant clinic as our exclusion restriction variable. It is expected that households living in close proximity to plant clinics are more likely to participate due to better exposure to information on plant clinics and lower transaction costs. On the other hand, we do not expect the distance to nearest plant clinic variable to directly affect our food security outcomes, especially after controlling for household proximity to other related sources of institutional support, such as input suppliers or agro-dealers, output markets and extension services. Using a simple falsification test following Di Falco et al. (2011), we checked the validity of the excluded instrument. The test results show that the distance to plant clinic variable significantly affects clinic participation decision (see Table A2 in the Online appendix) but not any of our food security outcome variables (see Table A3, Online Appendix), and thus providing support to the validity of our exclusion restriction.

When the error term of the selection equation (ε_i) is correlated with the error terms of the outcome equation of clinic participants (μ_{1i}) and non-participants (μ_{2i}), then we have an endogeneity problem. The ES model addresses the endogeneity bias issue by computing inverse Mills ratios from the selection equation (equation 2a) which are then added as auxiliary regressors to the outcome equations (equations 2b and 2c).

Table 1.
Summary statistics of covariates

Variable	Definition of variables	Full sample		Clinic users		Non-users	
		Mean	SD	Mean	SD	Mean	SD
Age	Age of household head (years)	49.59	13.34	49.94	11.94	49.35	14.10
Gender	Gender of household head (1 = male)	0.77	0.42	0.77	0.42	0.76	0.43
Education	Number of years of formal education of household head	4.99	3.29	5.68***	3.24	4.51	3.25
Household size	Number of household members	5.18	1.93	5.22	1.90	5.16	1.95
Dependency ratio	Household dependency ratio[a]	1.00	0.89	0.96	0.91	1.04	0.88
Land holding	Amount of land owned by household (hectares)	0.59	1.15	0.78***	1.54	0.46	0.73
Livestock holding	Number of livestock owned in Tropical Livestock Unit (TLU)	0.81	1.04	0.97***	1.29	0.69	0.80
Asset index	Household asset index[b]	0.00	1.43	0.33***	1.63	-0.24	1.23
Farmer group	A household member belongs to a farmer association (1 = yes)	0.32	0.47	0.40***	0.49	0.26	0.44
Credit access	Household has access to credit (1 = yes)	0.57	0.50	0.63***	0.48	0.52	0.50
Risk preference	Risk attitude of household (0 –10)[c]	6.44	1.76	6.80***	1.66	6.18	1.79
Distance to input shop	Distance from household to the nearest farm input shop (km)	2.46	2.49	2.93***	3.09	2.13	1.90
Distance to market	Distance from household to the nearest output market (km)	3.30	2.92	3.23	3.24	3.34	2.68
Distance to extension	Distance from household to the nearest extension office (km)	2.54	2.26	2.89***	2.59	2.29	1.97
Distance to plant clinic	Distance from household to the nearest plant clinic (km)	6.04	4.91	4.48***	3.54	7.58	4.64
	Number of observations	637		263		374	

Notes: *** denotes that the mean values for plant clinic users are significantly different from non-users at the 1% level.
[a]It was computed by taking the ratio of household members aged below 15 and above 64 to those aged 15–64.
[b]The asset index is based on household ownership of 11 durable assets. It was constructed using principal component analysis, following Filmer and Pritchett (2001).
[c]We applied the survey-based risk preference measure proposed by Dohmen *et al*. (2011), where 0 means not at all willing to take risks and 10 means fully prepared to take risks.

The coefficients from the ES model are then used to compute the average treatment effect on the treated (ATT), which compares the food security outcomes of participants with and without plant clinic participation.

2.4. Measurement of food security

Given the complex and multidimensional nature of food security, a suite of indicators has been developed for measuring household food security, ranging from simple experience-based metrics to relatively costly and time-consuming food intake and anthropometric measures (Barrett, 2010; Jones *et al.*, 2013). In this paper, we employ five indicators that are relatively quick and easy to implement and capture different dimensions of food security.

The first indicator is the months of inadequate household food provisioning (MIHFP). This is a subjective measure of household food access, and it refers to the number of months of the previous 12 that households had difficulties satisfying their food needs due to depletion of own food stocks or lack of money to purchase food (Bilinsky and Swindale, 2005). It reflects the ability of households to meet their food requirements over the course of a year, and thus measures the duration of the hungry season experienced by households. Considering that seasonal fluctuations in food availability have become an increasing challenge to many households in Rwanda (WFP, 2018), this indicator allows us to assess whether or not plant clinics help to buffer participating households against seasonal food shortages.

Our second and third food security indicators are based on the food insecurity experience scale (FIES). The FIES is an experience-based measure of the access dimension of food security that was developed by the Food and Agriculture Organization (FAO) through the Voices of the Hungry project and has been validated for cross-cultural use (Ballard et al., 2013). The FIES is also one of the 13 indicators that has been agreed upon for measuring progress towards the achievement of the SDG Goal 2 'Zero Hunger'. Using the household-referenced version of the FIES survey module, which comprises eight short questions with dichotomous responses, we ask households to report their experiences of varying degrees of food insecurity because of lack of money or other resources over a 30-day period. The eight questions relate to anxiety about household food supply, compromising on the quality and variety of food, insufficient food quantity and experiencing hunger (FAO, 2016). Our first FIES-based food security indicator was calculated by summing the scores from all eight questions to give raw scores ranging from 0 (food secure) to 8 (severe food insecurity). Thus, this indicator measures the degree of severity of the food insecurity condition of households one month prior to the survey. Secondly, following FAO (2015), we constructed a severe food insecurity indicator that is equal to one if a household's raw FIES score is 7 or 8; and zero otherwise.

The fourth food security indicator we use is the household dietary diversity score (HDDS). Dietary diversity indicators reflect both macronutrient and micronutrient adequacy and have been shown to be strongly associated with improved nutritional outcomes (Ruel, 2003; Headey and Ecker, 2013). Hence, we use this indicator to assess whether the potential yield and income effects of plant clinics translate into better nutritional quality of household diets. The HDDS was measured by the number of unique food groups (from a list of 12 food groups) consumed by household members in the home during the past 24 hours prior to the survey (Swindale and Bilinsky, 2006). The 12 food groups include cereal, white tubers and roots, legumes, nuts and seeds, vegetables, fruits, fish and other seafood, eggs, meat, milk and milk products, oils and fats, sweets, and spices, condiments and beverages.[2] Given the recognition that some of the food groups included in the HDDS (such as oil and fats) are micronutrient-poor food groups, we also use the women's dietary diversity score (WDDS), which better accounts for micronutrient adequacy of women's diets (Arimond *et al.*, 2010; FAO, 2011). The WDDS consists of nine food groups: starchy staples, dark green leafy vegetables, other vitamin A rich fruits and vegetables, other fruits and vegetables, organ meat, meat and fish, eggs, legumes, nuts and seeds and milk and milk products. Thus, the HDDS and WDDS range from 0–12 and 0–9 respectively, and both were estimated with the whole sample.

3. Results and Discussion

3.1. Descriptive statistics

Table 1 presents descriptive statistics for our sample, disaggregated by whether or not households participate in plant clinics. Households in our sample are mostly male-headed and have an average size of five members with a dependency ratio of one. The average household head is middle-aged and has only five years of formal education. Farms in Rwanda are very small (Ali and Deininger, 2015), and this is evident in our data, where the average land holding is 0.59 hectares. We find statistically significant differences between clinic users and non-users in most of the covariates. For instance, clinic users are significantly wealthier than non-clinic users in terms of land and livestock holdings, and durable goods. Additionally, a significant proportion of clinic users are members of farmer groups, have access to credit and have better educated household heads than non-clinic users. Compared to non-clinic users, clinic users live farther from farm input shops and agricultural extension offices, but are closer to plant clinics.

The upper panel of Table 2 reports the summary statistics for the eight questions that constitute the FIES. The results suggest that the majority of the sample households had experienced some level of food insecurity in the 30 days prior to the survey. For example, slightly more than two-thirds of the households were worried about insufficient food, were unable to eat healthy and nutritious food, consumed limited food varieties, and ate reduced portions of food. On the other hand, less than 10% of the households reported to have run out of food or gone a whole day without eating, which are related to moderate to severe levels of food insecurity (Ballard *et al.*, 2013). In our data, only 12.4% of households were food secure in the entire eight FIES items, suggesting that food security is still far from being attained in the study region. When comparing clinic and non-clinic users, we find that significantly more clinic users reported lower levels of food insecurity with respect to each of the eight FIES items.

Mean scores for our five food security outcome indicators are presented in the lower panel of Table 2. The mean FIES score is 3.76, signifying that the sample households are moderately food insecure. We find that 3% and 13% of clinic user and non-user households respectively are severely food insecure. The average reported months of household inadequate food provisioning is 2.33 months for clinic users versus 2.74 for non-clinic users. Thus, clinic users experienced a significantly shorter hungry season than non-clinic users. Turning to the two dietary diversity scores, the results show that the surveyed households, on overage, consumed food items from half of the 12 HDDS

[2]We employ a disaggregated set of food groups, which were then regrouped into the 12 HDDS food groups (Swindale and Bilinsky 2006).

Table 2.
Summary statistics for the food security indicators

Food security indicator	Full sample (n = 637)	Clinic users (n = 263)[a]	Non-users (n = 374)
1. Worried about not having enough food	0.66	0.60	0.71
2. Unable to eat healthy and nutritious food	0.70	0.61	0.76
3. Ate only few kinds of foods	0.73	0.65	0.78
4. Skipped a meal	0.46	0.35	0.54
5. Ate less amount of food	0.69	0.62	0.74
6. Ran out of food	0.08	0.04	0.11
7. Felt hungry but did not eat	0.34	0.25	0.41
8. Went without eating for a whole day	0.09	0.04	0.12
Food insecurity	3.76	3.15	4.18
Severe food insecurity	0.09	0.03	0.13
MIHFP	2.57	2.33	2.74
HDDS	5.99	6.34	5.74
WDDS	3.87	4.10	3.71

Note: [a]There is a statistically significant difference ($p < 0.01$) between clinic and non-users for all the indicators.

food groups and from nearly four of the nine WDDS food groups during the 24 hours preceding the survey. The results also show that the number of food groups consumed by clinic users is significantly higher than those consumed by non-clinic users, irrespective of the dietary diversity indicator.

Lastly, Figure 1 displays the mean consumption of the 12 HDDS food groups by clinic and non-clinic user households within a 24-hour period. There is high consumption of traditional staples such as cereals, white tubers and roots, and legumes, but low consumption of micronutrient-rich foods such as fruits, meat, egg, fish and milk or milk products. Significantly more clinic users consumed cereals, white tubers and roots, eggs, oils and fats and sweets-based foods than non-clinic users. Overall, our descriptive results suggest that plant clinic users are more food secure and consume a more diverse diet than non-clinic users, and thus point to a positive relationship between plant clinic participation and household food security. We will ascertain in our subsequent econometric analysis whether these observed differences in food security outcomes between clinic and non-clinic users can be causally attributed to plant clinics, after accounting for systematic differences between the two groups.

3.2. Effects of plant clinics on food security

Before looking at the results of the effects of plant clinics on household food security, we first briefly examine the first- and second-stage estimates of the ES models. Table A2 in the Online Appendix displays the first stage estimates of the ES models, and this shows the factors influencing participation in plant clinics.[3] We find, among

[3]Note that although the five first stage models in Table A2 are based on the same sample size, dependent variables and covariates, there are slight variations in the parameter estimates because they are jointly estimated with five different second stage outcomes (Tables A4 and A5) using full information maximum likelihood, which is an efficient method to estimate a switching regression (Lokshin and Sajaia, 2004).

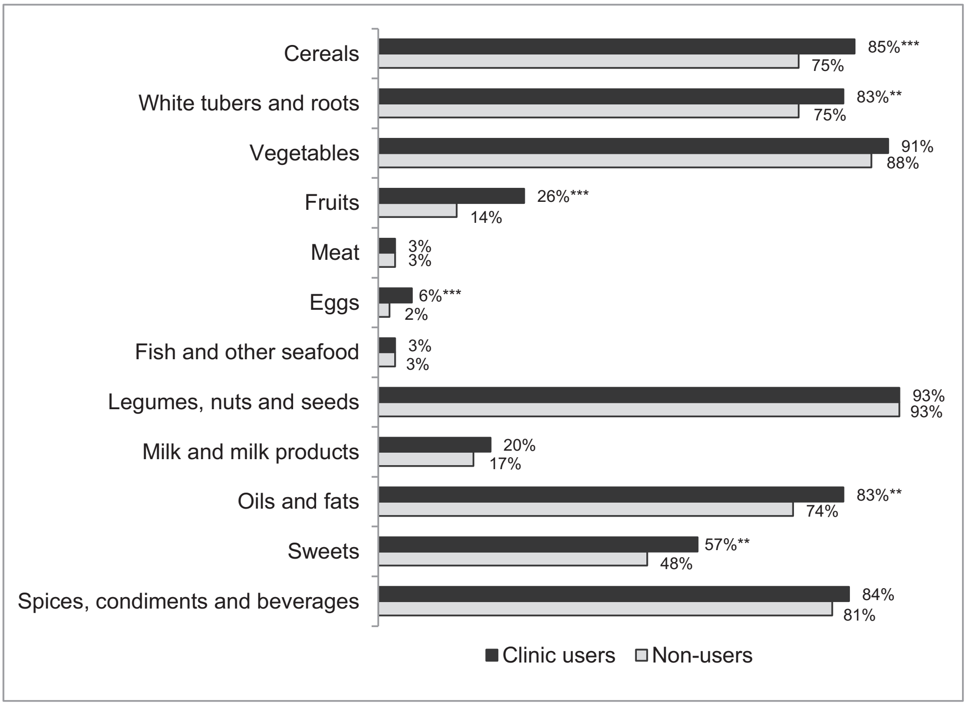

Figure 1. Food groups consumed by sample households
Note: *** and ** denote 1% and 5% significance levels, respectively.

other things, that households in close proximity to plant clinics have a higher probability of seeking plant health advice from plant clinics. This confirms that our instrument is relevant. The second stage results of the ES models, which show the determinants of food insecurity and dietary diversity, are presented in Tables A4 and A5 respectively in the Online Appendix. There are some notable differences in the coefficient estimates for the clinic users and non-clinic user regime equations, justifying the use of a switching regression approach. The coefficients on the rho 1 and rho 0 variables in the lower parts of Tables A4 and A5 measure the correlation between the error terms in the clinic participation and food security equations, and provide an indication of selection bias. The statistical significance of some of the rhos suggests that self-selection occurred in plant clinic participation, and this would have caused a bias in our impact estimates if not accounted for.

The predicted outcomes from the ES equations are used to compute the treatment effects of plant clinic participation, and the results are presented in Table 3. As previously mentioned, the ATT measures the mean difference between the actual outcomes of clinic users and what they would have gained if they had not participated in plant clinics. Results show that participation in plant clinics is significantly associated with a reduction in different aspects of household food insecurity. The ATT shows that participation in plant clinics contributes to a decrease in the months of household food insufficiency by one month for plant clinic users. We also find that participation in plant clinics leads to a significant reduction in food insecurity, particularly severe forms of food insecurity, as measured by the FIES. In particular, plant clinics helped

Table 3.
Treatment effects of plant clinics

	Mean outcome			
Outcome	Clinic participation	Non- participation	ATT	ATT in %
MIHFP	2.32	3.43	−1.11***	−32.36
Food insecurity	3.15	3.73	−0.58***	−15.55
Severe food insecurity	0.03	0.25	−0.22***	−88.00
HDDS	6.34	6.23	0.10***	1.61
WDDS	4.10	4.38	−0.29***	−6.62

Note: *** 1% significance level.

participating households to reduce their food insecurity and severe food insecurity situations by about 15% and 88%, respectively. The disaggregated results for the eight indicators of FIES in Table A6 in the Online Appendix confirm that the positive effect of clinics on food insecurity is predominantly driven by a reduction in moderate to severe level of food insecurity. For instance, participation in plant clinics is significantly associated with a 73% reduction in the probability that a household ran out of food, as well as 43% and 66% lower likelihoods that a household member was hungry but did not eat or went a whole day without eating respectively in the month leading up to the survey.

An examination of intermediate outcomes (Tables A7 and A8, Online Appendix) suggests that an increase in the adoption of multiple crop protection technologies and the resulting increase in maize yield, sales and income as well as the consumption of self-produced maize are among the underlying mechanisms through which plant clinics significantly affect household food security.

Looking at the results for the dietary diversity outcomes, the ATT estimates indicate that participation in plant clinics results in a 2% increase in household consumption of diverse diets. Conversely, we find that participation in plant clinics does not improve women's dietary diversity, but is actually associated with a decrease in their dietary diversity. The negative effect of plant clinics on women's dietary diversity, coupled with the relatively small percentage effect of plant clinics on household dietary diversity might suggest that plant clinics improve food security primarily by reducing losses of the crops that farmers send to plant clinics, which in Rwanda are mostly staples such as maize, cassava, beans, banana, and potato (POMS, 2019). This, in turn, improves the availability of staple food at the household level and allows households to smooth their food consumption over time, as confirmed by the finding that participating households have a lower likelihood of running out of food. Another plausible explanation could be that the potential income gains from plant clinic participation are spent on non-food goods, sustaining household food security or increased consumption of food groups that are not part of the WDDS, such as fats/ oils and sweets (as shown in Figure 1), without consideration given to food diversity or micronutrient adequacy of diet.

Overall, our findings imply that besides the positive technology adoption, yield and crop income effects of plant clinics reported by studies such as AIR (2018), Bett *et al.* (2018) and Silvestri *et al.* (2019), plant clinics also hold great potential for ameliorating household food security.

3.3. Impact heterogeneity

We showed in Table A2 in the Online Appendix that male- and female-headed households have an equal probability of participating in plant clinics. Accordingly, we examine whether both gender groups achieve similar food security benefits from participating in plant clinics. The results in Table 4 show that participation in plant clinics is significantly associated with improved food insecurity and dietary diversity (except women's dietary diversity) for all households regardless of the gender of the household head. The magnitudes of the ATTs are, however, higher for female-headed households compared to male-headed households, suggesting that clinic users in female-headed households are likely to benefit more in terms of a decrease in the duration of hungry season, a reduction in (severe) food insecurity and better household dietary quality than those in male-headed households.

This finding suggests that enhancing access to plant clinic services for women with decision-making power can result in greater improvement in household food security; thereby lending some support to the notion that increasing women's control over gains in agricultural productivity and income is likely to translate into food and nutritional improvements (Meinzen-Dick *et al*., 2012). A comparison of the characteristics of the female- and male-headed households in our sample indicates that the female-headed households are relatively asset-poor (in terms of livestock and durable assets); hence, another possible explanation for the heterogeneous impact by gender of household head is that the impacts of plant clinics may be greater for poorer households, which is partly confirmed by the results in Table 5. In addition, our data show that the female-headed households have significantly smaller household sizes and fewer dependents, and thus fewer people to feed, which may allow them to better meet their food needs than male-headed households.

Table 4.
Differential impacts by gender of household head

	Mean outcome			
	Clinic participation	Non-participation	ATT	ATT in %
MIHFP				
Female-headed households	2.13	3.35	−1.22***	−36.42
Male-headed households	2.37	3.45	−1.08***	−31.30
Food insecurity				
Female-headed households	2.93	4.13	−1.20***	−29.06
Male-headed households	3.22	3.61	−0.40***	−11.08
Severe food insecurity				
Female-headed households	0.03	0.30	−0.26***	−86.67
Male-headed households	0.03	0.24	−0.20***	−83.33
HDDS				
Female-headed households	5.91	5.78	0.12**	2.07
Male-headed households	6.46	6.37	0.10**	1.57
WDDS				
Female-headed households	3.85	4.27	−0.43***	−10.07
Male-headed households	4.17	4.42	−0.24***	−5.43

Note: *** and ** denote 1% and 5% significance levels, respectively.

Table 5.
Differential impacts by poverty likelihoods

	Mean outcome			
	Clinic participation	Non-participation	ATT	ATT %
MIHFP				
Non-poor	1.96	2.97	−1.01***	−34.01
Moderately-poor	2.33	3.43	−1.10***	−32.07
Extremely-poor	2.55	3.77	−1.22***	−32.36
Food insecurity				
Non-poor	2.71	3.01	−0.30***	−9.97
Moderately-poor	3.08	3.59	−0.51***	−14.21
Extremely-poor	3.63	4.54	−0.92***	−20.26
Severe food insecurity				
Non-poor	0.02	0.17	−0.15***	−88.24
Moderately-poor	0.03	0.25	−0.22***	−88.00
Extremely-poor	0.05	0.31	−0.26***	−83.87
HDDS				
Non-poor	6.65	6.51	0.14**	2.15
Moderately-poor	6.42	6.34	0.07	1.10
Extremely-poor	5.95	5.82	0.13**	2.23
WDDS				
Non-poor	4.37	4.49	−0.12*	−2.67
Moderately-poor	4.13	4.47	−0.34***	−7.61
Extremely-poor	3.84	4.14	−0.30***	−7.26

Note: ***, ** and * represent 1%, 5% and 10% significance levels, respectively.

We also explore the distributional food security effects of plant clinics by differentiating households according to their pre-treatment poverty status. Using the Progress out of Poverty Index (PPI), an asset-based poverty measure (Schreiner, 2016), we stratify the sample households into 'non-poor' (n = 96), 'moderately-poor' (n = 339) and 'extremely-poor' (n = 202) based on their likelihood of living below the national Rwanda poverty line prior to using plant clinic services.[4] Table 5 reports the treatment effect estimates for the three poverty likelihood groups. We find that participation in plant clinics significantly improves household food security irrespective of the poverty status of the participating household. There are, however, some noticeable differences in the magnitude of the treatment effects for the three groups of participating households. For instance, participation in plant clinics is associated with about 10%, 14% and 20% respective reductions in food insecurity for households with non-poor, moderately-poor and extremely-poor poverty likelihoods, suggesting that in terms of alleviating food insecurity (as measured by the FIES), extremely-poor households benefit more from using plant clinic services. Similar to the results for the aggregated analysis of plant clinic impacts on women's dietary diversity in Table 3, we find

[4]Non-poor means that the household is living above the national poverty line; moderately poor indicates that the household has less than 50% likelihood of living below the national poverty line; and extremely poor implies that the household has greater than 50% probability of living below the national poverty line.

Table 6.
Propensity score estimates of the impact of plant clinics

Outcome	Matching method	Mean outcome		ATT	SE	ATT in %
		Clinic users	Non-users			
MIHFP	Kernel matching	2.33	2.46	−0.13	0.16	−5.28
	Nearest neighbour	2.33	2.43	−0.10	0.18	−4.12
	Radius matching	2.33	2.48	−0.15	0.16	−6.05
Food insecurity	Kernel matching	3.18	3.65	−0.47**	0.20	−12.88
	Nearest neighbour	3.18	3.63	−0.45**	0.22	−12.40
	Radius matching	3.18	3.69	−0.51***	0.19	−13.82
Severe food insecurity	Kernel matching	0.29	0.44	−0.15**	0.06	−34.09
	Nearest neighbour	0.29	0.44	−0.15**	0.06	−34.09
	Radius matching	0.29	0.45	−0.15***	0.06	−33.33
HDDS	Kernel matching	6.30	6.00	0.30**	0.15	5.00
	Nearest neighbour	6.30	5.94	0.36**	0.17	6.06
	Radius matching	6.30	5.98	0.32**	0.15	5.35
WDDS	Kernel matching	4.08	3.97	0.11	0.11	2.77
	Nearest neighbour	4.08	3.99	0.09	0.12	2.26
	Radius matching	4.08	3.97	0.11	0.11	2.77

Note: *** and ** represent 1% and 5% significance levels, respectively.

that participation in plant clinics is negatively correlated with women's dietary quality, especially for the households moderately- and extremely-poor poverty likelihoods.

Taken together, these results suggest that participation in plant clinics contributes to improved household food security, regardless of the poverty status of the household or whether the household is headed by a male or female.

3.4. Robustness checks

Recognising that the results from the ES models may be sensitive to its distributional (trivariate normal distribution of errors) and exclusion restriction assumptions, we also use PSM techniques to ascertain the robustness of the above results. PSM involves matching clinic users with non-clinic users that are similar in terms of observable variables. The matching variables used are similar to the control variables in the ES models. As a further robustness check, we use three different matching methods: kernel matching with a bandwidth of 0.06, nearest neighbour matching, and radius matching with a calliper of 0.05.[5] While PSM controls for only observable characteristics, it has the advantage of not imposing any functional form or exclusion restriction assumptions. Figure A2 in the Online Appendix shows that there is substantial overlap in the distribution of the propensity scores of clinic users and non-users, suggesting a satisfaction of the common support condition. Additionally, the covariate balancing test results displayed in Table A9 in the Online Appendix show low pseudo-R^2, low mean bias and insignificant log-likelihood values after matching, and these are all evidence of successful matching between clinic users and non-users (Caliendo

[5]See Caliendo and Kopeinig (2008) for a detailed discussion of the three matching strategies.

and Kopeinig, 2008). After confirming that our matching methods have passed the various tests of matching quality, we estimate the ATTs, and the results are presented in Table 6.

The results are highly consistent across the three matching methods. We find that using plant clinic services is associated with a reduction in the length of period of food shortages, but unlike the ES models, the ATT estimates are not statistically significant. Results also show participation in plant clinics decreases the probability of food insecurity and severe food insecurity by 13% and 34%, respectively. The lower impact estimates from the PSM approach relative to estimates from the ES models may be due to potential biasing effects of unobserved heterogeneity when using PSM. We also observe that plant clinics significantly enhance the dietary diversity of participating households by about 5–6%. Finally, in contrast to the ES model results, plant clinic participation exerts a positive, but insignificant effect on women's dietary diversity. Overall, the PSM results confirm the positive role of plant clinics in alleviating food insecurity (as measured by the FIES) as well as in improving household dietary diversity.

4. Conclusion

We use data on 637 maize-growing households across three provinces of Rwanda to evaluate the food security effects of plant clinics, a novel extension approach that aims to mitigate crop losses and improve household food security through the provision of demand-driven pest diagnosis and management advice to farmers. While a few existing studies have shown that plant clinics increase farmers' pest knowledge, technology adoption and crop yields (Bett *et al.*, 2018; AIR, 2018; Silvestri *et al.*, 2019; Tambo *et al.*, 2020), this study is the first to analyse whether participation in plant clinics also leads to improved food security, which is an important development outcome. Methodologically, we contribute to the literature by using the food insecurity experience scale (FIES), which is one of the globally agreed indicators for tracking progress towards the achievement of SDG 2.

Our results show that participation in plant clinics is significantly associated with a reduction in household food insecurity, as measured by food security metrics such as the FIES, the months of inadequate household food provisioning (MIHFP), and the household dietary diversity score (HDDS). In particular, plant clinics contribute to a decrease in the period of food shortage by one month, a 22 percentage points (or 88%) reduction in the severity of food insecurity, and a 2% increase in the number of food groups consumed among participating households. On the other hand, we found that plant clinics are negatively associated with women's dietary diversity. We also observed that the estimated positive effects of plant clinic participation on household food security are particularly pronounced for female-headed households.

Taken together, our findings suggest that the plant health advisory services provided by plant clinics are contributing to improved household food security, and this is particularly noteworthy in light of the rise in world hunger in recent years (FAO *et al.*, 2019) and the increasing threats from invasive pests (Early *et al.*, 2016). The results imply that policy interventions that encourage the establishment of and farmers' participation in plant clinics can contribute to global efforts to achieve a zero-hunger world by 2030. Given that our results and those of previous studies (e.g., Karubanga, 2017; Majuga *et al.*, 2018) have shown that physical distance and lack of awareness are among the key barriers to plant clinic participation, efforts to expand the reach of plant clinics could include better publicity (through, for instance, linkages with other extension activities such as farmer field schools); the rotation of plant clinics between different communities (i.e., mobile plant clinics); and building the capacity of extension workers in plant health diagnostics and advice. Moreover, our results suggest that strategies aimed at improving women's access to plant clinic services may lead to greater food security gains. Potential strategies may include training more female plant doctors, establishing clinics in areas accessible to women, holding clinic sessions at times convenient for women, and running women-only plant clinics in some cultural settings (David *et al.*, 2019).

Our finding that plant clinics do not improve women's dietary diversity, which reflects micronutrient adequacy, suggests that further efforts are needed to leverage plant clinics for better nutrition outcomes. Such efforts may include an accompanying programme of nutrition education, which has been found to be associated with positive nutrition outcomes, including women's dietary diversity (Murendo *et al.*, 2018). Given the importance of nutrition to human health, one option would be to explore the possibility of broadening the package of services offered at plant clinics to include nutritional advice under the umbrella of 'one health'.

Finally, some limitations should be mentioned. First, our study relies on cross-sectional survey data which does not allow us to explore the long-term dynamics of plant clinic participation and household food security. Second, we use data from only one of the countries where the plant clinic extension model is being applied. Further research using panel data and in different geographical settings will add to the understanding of the food security implications of plant clinics. The panel data will also allow us to better control for unobserved heterogeneity. Third, we identified a number of transmission mechanisms through which plant clinics could influence food security, but our data did not allow us to examine all of them empirically. We leave this also for future work.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table A1. Summary statistics for main variables used for selecting sample households.

Table A2. First stage results (Determinants of plant clinic participation).

Table A3. Falsification test.

Table A4. Second stage results (Determinants of food insecurity).

Table A5. Second stage results (Determinants of dietary diversity).

Table A6. Impact of plant clinics on FIES indicators.

Table A7. Descriptive statistics for intermediate outcomes.

Table A8. Effects of plant clinics on intermediate outcomes.

Table A9. PSM matching quality tests.

Figure A1. Study area.

Figure A2. Kernel density distribution showing overlap between clinic users and non-users.

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