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Gender-differentiated impacts of plant clinics on maize productivity and food security: Evidence from Zambia

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ABSTRACT

The United Nation's declaration of 2020 as the International Year of Plant Health underscores the crucial role of crop protection in achieving the sustainable development goals. In this article, we analyse the gendered impacts of plant clinics—an innovative extension approach that aims to help smallholder farmers to lose less of their crops to pests through the provision of plant health diagnostic and advisory services. In particular, we investigate whether male and female farmers accrue similar benefits, in terms of technology adoption, maize productivity and food security, from participating in plant clinics. We use gender-disaggregated plot-level data from maize producers in Zambia. Applying doubly robust estimators, we find that participation in plant clinics stimulates the adoption of multiple pest management strategies, which boost maize yield and income by 14% and 27% respectively, and ultimately help to stave off food insecurity. A disaggregated analysis shows that both male and female farmers achieve positive outcomes from using plant clinic services, but the effects are disproportionately greater for male farmers. We also observe heterogeneous impacts for female household heads and female spouses, reflecting differences in decision-making power within the household. The findings suggest that plant clinics can play a significant role in helping male and female farmers address crop health problems and reduce transitory food insecurity, but female participants (particularly female spouses) will need additional support if the goal is to bridge the gender gap in agricultural productivity.

1. Introduction

Pests, including insects, pathogens and weeds continue to pose a major threat to global crop production and food security. The United Nations General Assembly's declaration of 2020 as the International Year of Plant Health emphasises the fundamental importance of crop protection in achieving the sustainable development goals (SDGs). Yearly, between 26% and 40% of potential global crop production is reportedly lost to pests (OECD/FAO, 2012). Unfortunately, climate change and increases in international trade and travel are fostering the introduction and spread of new pests (Early et al., 2016), which may further exacerbate the global food insecurity situation. For example, since its outbreak in West Africa in 2016, the highly destructive fall armyworm (*Spodoptera frugiperda*) pest has spread rapidly to over 60 countries in Africa and Asia, and is threatening the livelihoods of millions of smallholder farmers (CABI, 2020).

At the same time, it is widely recognised in development discourse that achieving gender equality and women's empowerment is central to economic growth and sustainable development (World Bank, 2011; Gates, 2014; Woetzel et al., 2015). This recognition is highlighted in SDG 5 on gender equality. Women make important contributions to agricultural production and food security, but face more constraints than men in their access to productive resources and services, including agricultural extension (FAO, 2011; O'Sullivan, Rao, Raka, Kajal, & Margaux, 2014; Quisumbing et al., 2014, 2019). Estimates from FAO (2011) suggest that bridging the gap between men and women in access to agricultural resources could increase yields on women's farms by 20%–30%. Evidence also shows that increasing women's access to extension information and services may help reduce gender knowledge gap and spur technology adoption (Lambrecht et al., 2016), which could in turn narrow the gender productivity gap (Ragasa, Berhane, Tadesse, & Taffesse, 2013), and improve household food

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security (Pan, Smith, & Sulaiman, 2018). In this article, we assess whether there are gendered differences in the impacts of plant clinics—an innovative extension model that provides plant health diagnostic and information services to smallholder farmers in many developing countries. In particular, we examine whether male and female farmers accrue similar benefits from participating in plant clinics in terms of improved management of crop pests, crop productivity and food security.

Agricultural extension has long been recognised as pivotal to building farmers' technical capacity and providing farmers with timely access to appropriate information (Anderson & Feder, 2007), which is especially relevant when they face new challenges such as pest outbreaks. In the past decades, many agricultural development programmes have applied one or several extension models, accompanied by studies to determine their effectiveness. These include: training and visit (T&V) extension system (Bindlish & Evenson, 1997); private or co-financed extension (Dinar & Keynan, 2001); farmer field schools (Davis et al., 2012; Larsen & Lilleør, 2014); other participatory methods of extension (Läpple, Hennessy, & Newman, 2013); ICT-enabled extension services (Aker, 2011; Tambo et al., 2019); and, more recently, plant clinics (Silvestri et al. 2018; Tambo, Uzayisenga, Mugambi, Bundi, & Silvestri, 2020). Plant clinics are meeting places where farmers bring in samples of their infested crops and receive diagnostic and management advice from extension workers trained as plant doctors. The plant clinics are supported by Plantwise, a global programme managed by CABI that aims to improve food security and rural livelihoods by reducing crop losses.

The Plantwise programme has a gender strategy that seeks to ensure that all plant clinic activities are conducted in a way that promotes gender equality and that all outputs and achievements are analysed from a gender perspective (Finegold & Williams, 2012). Moreover, the programme has taken a number of steps to ensure that female farmers are not disadvantaged in their access to plant clinic services. Examples of such actions include: training of more female plant doctors; incorporating modules on gender within plant doctor training curriculum; establishing plant clinics in areas accessible to women; female-targeted publicity campaign; holding clinic sessions at times convenient for women; linking plant clinics with existing women's groups; and running female-only plant clinics in some cultural settings (CABI, 2019; Terefe, 2020). These actions suggest that the Plantwise programme encourages a gender-aware approach and is designed to deliver plant health extension services that are inclusive and accessible to all types of farmers.

In spite of the seemingly efforts to embed gender perspectives in plant clinic activities, there has been no attempt to examine whether plant clinics are generating any gender differentiated impacts. The growing body of evidence on the effectiveness of the plant clinic extension initiative has mostly focused on the household as the unit of observation (Bentley et al., 2011; Silvestri, Macharia, & Uzayisenga, 2019; Tambo, Uzayisenga, et al., 2020), which precludes the analysis of gender and intra-household dynamics of plant clinic participation and impacts. The few gender-related studies on plant clinics have only looked at gender differences in access to and quality of advice and services provided at plant clinics (Karubanga, Matsiko, & Danielsen, 2017; Lamontagne-Godwin, Williams, Bandara, & Appiah-Kubi, 2017; Musebe et al., 2018; Williams & Taron, 2020). While these studies have shown that plant clinics are helping to reduce gender gaps in extension access, it is still unclear whether plant clinics can also provide equitable benefits and contribute to a reduction in gender disparities in technology adoption and agricultural productivity. The current study aims at filling this knowledge gap using a recent gender disaggregated plot-level data from Zambia.

Zambia is a particularly interesting case to study the gendered impacts of plant clinics. First, an increasing number of female farmers in the country have been using plant clinic services in recent years (Williams & Taron, 2020). Second, male and female farmers tend to seek advice on similar plant health problems (POMS, 2020), thus allowing a gender comparison. Third, while there is an increased effort to promote gender-responsive agricultural extension services in Zambia (Mofya-Mukuka & Kabisa, 2016), gender-sensitive assessments of agricultural extension are limited, partly due to lack of gender-disaggregated data (FAO, 2018). Our study will help to bridge this gap. Lastly, according to the global gender gap index, Zambia is ranked 45 out of 153 countries in 2020 compared to a rank of 116 out of 145 countries in 2015, suggesting that the country is making rapid progress in closing gender gaps (World Economic Forum, 2015, 2020).

The research questions addressed in this study include: (1) Do plant clinics in Zambia foster technology adoption and generate positive productivity and welfare outcomes? (2) Does female participation in plant clinics have similar impact on pest management, agricultural productivity and food security compared to male participation? (3) Do female heads and female spouses equally benefit from participating in plant clinics, given that the latter group may have limited decision-making power to implement the advice received at plant clinics? (4) Does participation in plant clinics by male (female) farmers affect technology adoption on male (female) managed plots only, or does the knowledge gained from clinics trickle down to benefit all household plots equally, regardless of the gender of the participant and the plot manager?

By answering these questions, we contribute to the literature on extension achievements and gender gap in agriculture in several ways. First, we expand on and test the generalisability of findings from the few studies that have investigated the impacts of plant clinics on farm-level outcomes (e.g., Bentley et al., 2011; Silvestri et al., 2019; Tambo, Uzayisenga, et al., 2020). Unlike these previous studies, we use plot-level gender disaggregated data that allow us to control for a number of plot characteristics, including the gender of the plot manager. Second, to our knowledge, ours is the first study to empirically examine the gender-differentiated impacts of plant clinics since this mode of extension delivery was initiated nearly two decades ago. Third, we contribute to the broader literature on the impact of extension by adding to the thin evidence base on the gendered outcomes of extension services (Ragasa et al., 2013; Lambrecht, Vanlauwe, & Maertens, 2016; Ragasa et al., 2019; Akter, Erskine, Spyckerelle, Branco, & Imron, 2020). These studies focused on general agricultural information and outcomes related to soil-restoring and yield-enhancing techniques as well as food security. By contrast, we focus on personalised plant health information and crop protection strategies as pathways for achieving greater productivity and food security.

The rest of the paper is organised as follows. Section two provides a brief background on plant clinics in Zambia. The third section describes the data sources and estimation methods. Descriptive and empirical results are presented and discussed in section four, and section five concludes the paper.

2. Plant clinics in Zambia

The government of Zambia promotes pluralistic extension systems to meet the diverse and complex needs of farmers, which include technical advice, inputs, credit and market (Burrows, Bell, & Rutamu, 2017). One of the important extension models embraced in the country is plant clinics. The plant clinic extension approach was initiated in Zambia in 2013 by the Ministry of Agriculture (MoA) in collaboration with the Plantwise programme. The MoA, through the Department of Agriculture (DoA) and the Zambia Agriculture Research Institute (ZARI), is the national organisation responsible for the implementation of plant clinics in the country. The plant clinic initiative has attracted interest from several partners, such as the University of Zambia, World Vision and the Netherlands Development Organisation (SNV) who also support the training of plant doctors and the running of the clinics (CABI, 2019). At the inception, 13 plant clinics were established in six districts across three provinces. Currently, there are 121 plant clinics operating in 39 districts across all of the country's 10 provinces. These clinics are staffed by 352 plant doctors who have been trained on topics related to pest identification and diagnosis, the operation of a plant clinic and the advising of farmers about plant health issues based on the principles of integrated pest management (IPM).

The plant clinics in Zambia offer open services (free-of-charge) at predetermined times (usually fortnightly) at easily accessible locations near health posts, markets, schools, churches and dambos. Each clinic is manned by one or two plant doctors who have access to basic diagnostic materials, including knives, hand lens, fact sheets, reference books on pests, and in some cases tablet computers and smart mobile phones. Any farmer can send a sample of any ailing crop to the clinics, and a plant doctor will examine the sample, diagnose the problem and provide management advice. To be able to render accurate diagnostic and advisory services, the plant doctors have access to the Plantwise Knowledge Bank, which is a repository for pest data and actionable plant health information. Each plant clinic attendee is issued a handwritten or digital prescription form, which records basic information about the farmer, crop brought to the clinic, symptoms of pest attack, diagnosis and recommendations. These data are immediately or eventually entered into the Plantwise Online Management System (POMS).

The POMS database show that from 2013 to 2019, the plant clinics in Zambia attended to about 12,000 farmers' queries on roughly 100 crops. About 60% and 40% of these queries were submitted by male and female clinic users, respectively. Maize, tomato, rape (Brassica napus), mango, and cabbage were the most common crops brought to the clinics, with maize comprising more than half of the queries. Fall armyworm (FAW) was the most popular plant health problem, making up 65% of the queries on maize.[1] These numbers from the POMS data are indicative that the plant clinic extension approach has grown in popularity and importance in Zambia, particularly in the wake of the FAW invasion.

3. Data and methods

This section describes the data used in the analysis, as well as the estimation methods and outcome variables.

3.1. Data sources

Our empirical analysis draws on plot-level gender-disaggregated data from a survey of 837 smallholder households and 1048 maize plots in Zambia. The data focus on the 2018/2019 maize cropping season that spanned from November 2018 to June 2019. The study concentrates on maize because it is the main food crop in Zambia and has by far the highest number of clinic queries. The focal pest is FAW, as it constitutes about 80% of the queries on maize for the cropping season under study.

Prior to the survey, it was observed from the POMS database that about 2,300 farmers had brought FAW queries to the plant clinics in Zambia during the 2018/2019 cropping season, and this served as our sampling frame for clinic users. Given that these 2,300 farmers are scattered across the 121 plant clinics in the country, a multi-level stratified sampling approach was used to select the clinic and non-clinic users. In the first stage, plant clinic users were stratified based on agro-ecological zones (AEZs). Zambia is divided into three AEZs (I, II and III). Zone II is subdivided into two zones: IIa and IIb. Farm households were sampled from AEZs I, IIa and III, which comprise the major maize-growing areas of the country (Smale, Moursi, & Birol, 2015).[2] The data cover seven (Central, Copperbelt, Eastern, Luapula, Lusaka, Muchinga and Northern) out of the 10 provinces in the country (see Fig. 1). Six, twelve, and seven agricultural camps[3] where plant clinics have been sited (hereafter referred to as plant clinic camps) were selected from AEZs I, IIa and III respectively, based on the density of plant clinics, the number of queries on FAW, and the importance of maize production. In each selected plant clinic camp, about 5 to 20 male and female clinic users each were then randomly sampled proportionate to the number of FAW queries. The POMS database was used to confirm that the selected male and female clinic users had actually visited plant clinics in the past cropping season to seek advice related to FAW.

To create a valid comparison group, the non-clinic users were selected from agricultural camps that were as similar as possible to the plant clinic camps with respect to agro-ecological zones, crops grown, incidence of FAW pest, and infrastructural development. First, for each selected plant clinic camp, we identified a comparable camp with no plant clinic activities. We ensured that a selected plant clinic camp and its corresponding non-clinic camp were located within the same AEZ and district but were not geographically adjacent so as to mitigate potential spillover effects. Then in each control camp, between 10 and 20 maize-producing households were randomly selected from household lists provided by camp extension officers. The first section of the survey tool included filter questions to ensure that the selected non-clinic users are maize farmers who experienced FAW attacks on their maize crops during the past cropping season and had never used plant clinic services. Thus, our data came from 25 plant clinic camps and 25 comparable non-clinic camps across the three AEZs. In total, our sample included 837 maize-growing households, comprising 444 clinic users (227 and 217 male and female clinic users, respectively) and 393 non-clinic users (234 and 159 male- and female-headed households, respectively).

Data were collected between August and September 2019 by 17 enumerators who were trained and supervised by the researchers. The enumerators used tablet-based questionnaires that contained modules (most of which were gender disaggregated) on household composition and characteristics; participation in plant clinics; maize production and decision-making; FAW infestation and management practices; access to infrastructure to institutional support services; social capital and risk attitude; household assets; food security indicators; and a bidding game to elicit willingness to pay for plant clinic services. Camp-level rainfall data for the 2018/2019 cropping season were obtained from the Climatology Resource for Agroclimatology of NASA (http://power.larc.nasa.gov).

[1] The most important queries brought to the plant clinics in Zambia between 2013 and 2019 are presented in Table S1 in the online supplementary material.

[2] AEZ I: low-rainfall area (annual rainfall <800 mm), hot and drought-prone region; AEZ IIa: Rainfall and soils are more favourable for farming (annual rainfall = 800–1000 mm); AEZ III is a higher rainfall area (>1000 mm of rain/year) but has low fertile soils (Smale et al., 2015).

[3] A camp is the lowest tier of agricultural administration in Zambia and is manned by a camp extension officer.

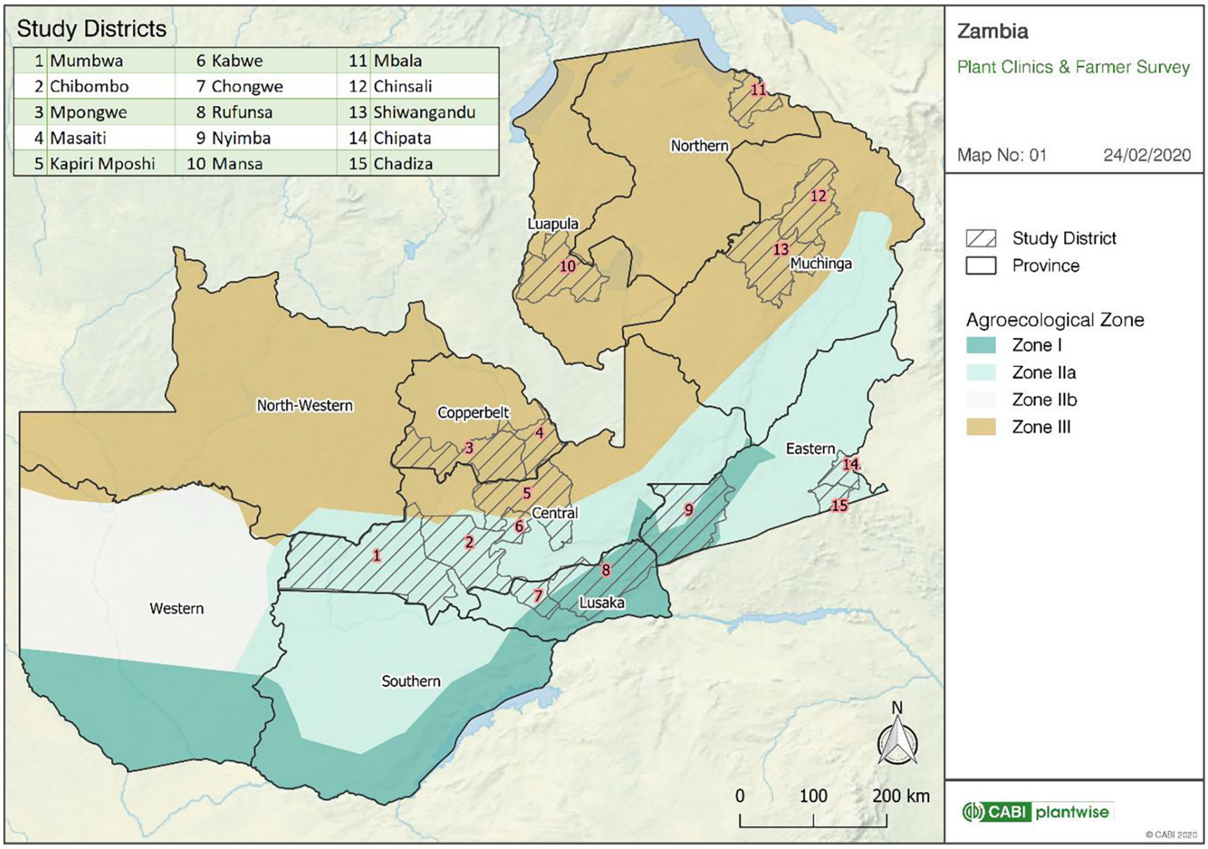

Fig. 1. Map of Zambia showing agro-ecological zones, provinces and location of the study districts.

3.2. Empirical strategy

As previously mentioned, the main goal of this study is to investigate if male and female farmers benefit equally from participating in plant clinics. Given the results from previous studies on the impact of plant clinics (Silvestri et al., 2019; Tambo, Uzayisenga, et al., 2020; Tambo, Uzayisenga, Mugambi, & Bundi, 2021), we hypothesise that participation in plant clinics enhances farmers' knowledge of crop pests and spurs the adoption of improved pest management practices, resulting in increased crop yields and incomes, and ultimately the alleviation of food insecurity. We also hypothesise that plant clinics improve female farmer's access to extension services (Williams & Taron, 2020), thereby contributing to women's empowerment in agriculture (Rivera & Corning, 1990). The income and empowerment gains from female participation in plant clinics can increase women's control over income and subsequently improve household food security (Meinzen-Dick, Behrman, Menon, & Quisumbing, 2012). On the other hand, plant clinics can worsen gender productivity gap if female famers face barriers to implementing the advice received at the clinics. Moreover, as observed in other gendered studies on extension (Ragasa, Aberman, & Mingote, 2019), participation in plant clinics can be potentially disempowering if it places an extra responsibility on female spouses who may have little power to implement lessons learned.

We estimate the impact of male or female participation in plant clinics on technology adoption and productivity outcomes at the plot level and on food security outcomes at the household level. We provide details on the outcome variables later. A farmer i in our sample has two potential outcomes: Y^1 (if farmer i participates in plant clinics and Y^0 (if farmer i does not participate in plant clinics). The causal effect of plant clinic participation for farmer i is the difference between Y_i^1 and Y_i^0. The challenge of analysing the effects of plant clinics is that only Y_i^1 or Y_i^0 can be observed for farmer i, but never both at the same time. Consequently, we assess the impact of plant clinics by comparing Y^1 of clinic users with Y^0 of non-clinic users. Given that participation in plant clinics is not based on random assignment, there may be systematic differences between clinic users and non-users and thus a simple mean difference between Y^1 and Y^0 may yield biased impact estimates. To attenuate this bias, we use the inverse-probability-weighted regression adjustment (IPWRA) estimation technique, also known as the doubly robust estimator, which combines regression and propensity score weighting approaches. Thus, we employ this method to account for systematic differences between clinic users and non-users, thereby making them sufficiently similar so that observed differences between Y^1 and Y^0 can be attributed to plant clinic participation.

The doubly robust method follows three steps. First, the probability of participating in plant clinics (treatment model) is estimated using a logistic model, and the inverse-probability weights are computed from the predicted probabilities. Secondly, weighted regression models of the outcome for each treatment group are fitted to obtain the expected outcomes of the probabilities of participation and non-participation in plant clinics, using the estimated inverse-probability weights from step one. We use probit, Poisson and ordinary least squares (OLS) models for binary, count and continuous outcome variables, respectively. Lastly, the mean outcomes for clinic and non-clinic participants are used to derive the average treatment effects of the treated (ATT):

$$ATT = E\left[Y^1 - Y^0 | P = 1\right] = E\left[Y^1 | P = 1\right] - E\left[Y^0 | P = 0\right] \quad (1)$$

where E [ ] is the expected value operator; P is a binary variable indicating whether a farmer is a plant clinic participant or not; and all the other variables are already defined. The ATT measures how plant clinics affect the outcomes for participating farmers. Note that we estimate separate treatment and outcome models to compare (a) clinic and non-clinic users, (b) male clinic users and non-clinic users, (c) female clinic users and non-users, (d) female heads and non-clinic users, and (e) female spouses and non-clinic users.

A particularly attractive advantage of the doubly-robust method over other selection-on-observables methods such as propensity score matching is that it is robust to misspecification in either the treatment model or the outcome model. In other words, the ATT is consistently estimated even if only one of the models is correctly specified (Imbens & Wooldridge, 2009).

As is typical with selection-on-observables designs, the identification of the ATT in the doubly robust framework relies on two key assumptions: the weak common support or overlap condition and the weak unconfoundedness assumption (Imbens, 2004). The weak overlap assumption requires that each farmer in our sample has a nonzero probability of not participating in plant clinics. We examine whether or not this assumption is violated by visually checking the extent of propensity score overlap. Furthermore, we check for covariate balancing using the overidentification test proposed by Imai and Ratkovic (2014). The weak unconfoundedness assumption implies that conditional on observable covariates, potential untreated outcomes (Y^0) are independent of treatment assignment (P). This is a rather strong assumption because it is possible that clinic users and non-clinic users may differ in unobservable characteristics, such as ability, personal motivation, risk attitude and entrepreneurial skills, which may affect our outcome variables.

To mitigate potential bias from unobserved factors, the treatment groups (clinic and non-clinic users) were selected from similar agroecological and production environments (e.g., rainfall, crops grown and pest incidence), and a rich set of covariates were included in the treatment model to obtain the inverse-probability weights. Motivated by literature on the determinants and impacts of participation in plant clinics and other extension programmes (e.g., Lambrecht et al., 2016; Silvestri et al., 2019; Tambo et al., 2019), the covariates include proxies for human capital and labour availability (age, gender and education of household head, household size and dependency ratio); household asset endowments (land area, livestock holdings and durable assets); access to institutional factors (credit, off-farm activities, and distance to input market and extension service providers); a measure of risk preference; and location dummies to capture unobserved heterogeneity across agro-ecological zones (see Table 1). Note that the covariates in the outcome model include a number of plot-level factors such as plot size, perception of plot fertility and slope, plot distance to homestead and gender of plot manager, in addition to those included in the treatment model.

Furthermore, we include a measure of farmers' willingness to pay (WTP) for plant clinic services as a conditioning variable to compute the inverse-probability weights. This was inspired by the works of Verhofstadt and Maertens (2014) and Bellemare and Novak (2017) who used a similar approach to control for unobserved effects in their impact analyses with propensity score matching. This approach is premised on the assumption that the WTP estimates serve as a reasonable proxy for farmers' marginal utility of participating in plant clinics and are likely to be closely related to a range of unobservable factors that influence farmers' decision to participate in plant clinics (Bellemare & Novak, 2017). Following Onwujekwe and Nwagbo (2002) and Verhofstadt and Maertens (2014), farmers' WTP for plant clinic services was estimated through an iterative bidding game, carried out with clinic and non-clinic users (see S2 in supplementary material for details). This widely used contingent valuation technique has been found to be more appropriate and reliable in developing country settings, as in our study (Whittington, 1998; Onwujekwe & Nwagbo, 2002). For comparison purposes, we report two sets of ATT estimates: (1) under the weak unconfoundedness assumption and (2) under an "extra" weak unconfoundedness assumption in which we attempt to further weaken this assumption by conditioning on the WTP variable.

3.3. Outcome variables

We estimate the impact of plant clinics on outcome indicators related to crop protection technology adoption (immediate outcome), productivity (intermediate outcome) and food security (final outcome). Our study focuses on maize producers; hence, the first outcome relates to the adoption of pest management strategies against the most common and destructive pest of maize, which is FAW. Given that plant doctors have been trained to advise farmers to use multiple methods of pest control (IPM), our main indicator for the adoption of FAW management strategies is measured as the number of prevention and control practices that a maize producer has adopted for the management of FAW. Additionally, we analyse differential effects on FAW management advice provided by plant doctors. The plant doctors' advice to farmers can be categorized into four groups: monitoring, cultural control, mechanical control and chemical control.

Monitoring comprises regular scouting of maize after germination to check for signs and symptoms of FAW as well as record-keeping to aid in FAW management decision-making. Cultural control methods include avoiding late or staggered planting; regular weeding to remove alternative host plants; fertilization to support healthy plant growth so that the maize plants can withstand FAW infestations; and intercropping and rotation of maize with non-host crops such as cassava, cowpea and groundnuts. Mechanical control is composed of handpicking/crushing of egg masses and caterpillars or rogueing of infested plants, while chemical control refers to the use of pesticides.[4] Our crop productivity outcome involves maize yield and net maize income. Maize yield is measured as the total amount of maize harvested in kg per hectare of land, while net maize income is defined as gross maize income minus variable costs, such as seed, fertiliser, herbicide, insecticide, mechanization, hired labour, transport and marketing expenses.

To assess food security, we use three simple and easy-to-implement measures that capture the access dimension of food security. The first indicator is the length of food gap, also known as months of adequate household food provisioning (Bilinsky & Swindale, 2007). It is based on responses to the question "how many months out of the past 12 months did you have difficulties satisfying your households' food needs due to depletion of own food stocks or lack of money to purchase food". Thus, it measures the ability of households to satisfy their food needs over the course of a year. This indicator allows us to assess whether or not plant clinics help to cushion participating households against seasonal food shortages, which is important in light of the worsening food insecurity situation in Zambia in the past year (FAO, 2020).

The second and third food security metrics are based on the food insecurity experience scale (FIES), which is one of the proposed indicators for tracking progress towards the achievement of the SDG 2 of zero hunger. Using the household-referenced version of the FIES survey module (FAO, 2016a), which comprises eight short questions with dichotomous responses, we ask households to report their

[4] Given the negative effects of pesticides on humans and the environment, plant doctors are obliged to recommend safe, appropriate and judicious use of pesticides. Assessing the types of pesticides used as well as the pesticide handling practices of the surveyed farmers is beyond the scope of this study.

Table 1
Summary statistics of key household variables.

Variable	Description	Full sample	Clinic users[a]	Non-users	Male users[b]	Female users
Age	Age of household head (years)	50.34 (13.23)	49.61 (13.04)	51.18 (13.04)	48.71 (12.88)	50.56 (13.17)
Gender	Gender of household head (1 = female)	0.33	0.26***	0.40	0.02***	0.51
Education	Number of years of formal education	7.69 (3.44)	7.83 (3.27)	7.53 (3.60)	8.16** (3.22)	7.48 (3.31)
Household size	Number of household members	7.08 (3.21)	7.08 (2.82)	7.09 (3.61)	7.31* (2.93)	6.84 (2.70)
Dependency ratio	Household dependency ratio[c]	1.26 (1.11)	1.18** (1.08)	1.35 (1.24)	1.12 (1.05)	1.25 (1.09)
Farm size	Household's cultivated land area (ha)	2.80 (2.81)	3.04*** (2.77)	2.53 (2.83)	3.53*** (3.06)	2.54 (2.33)
Off-farm activity	Household member has off-farm job (1/0)	0.48	0.45	0.50	0.47	0.45
Credit constrained	Household needed credit but did not get it (1/0)	0.23	0.23	0.24	0.24	0.21
Asset index	Household asset index[d]	−0.10 (1.62)	−0.03 (1.56)	−0.18 (1.69)	0.33*** (1.45)	−0.41 (1.58)
Livestock holding	Household livestock holding in Tropical Livestock Unit (TLU)	2.47 (4.75)	3.21*** (5.25)	2.21 (4.05)	4.26*** (5.99)	2.11 (4.08)
Distance to agro-dealer	Distance from household to the nearest agro-dealer (km)	15.11 (13.85)	16.13** (13.78)	13.95 (13.86)	16.98 (14.82)	15.23 (12.58)
Distance to extension	Distance from household to the nearest extension office (km)	9.80 (10.15)	10.00 (11.52)	9.58 (9.06)	10.00 (10.30)	10.01 (11.85)
Farmer group	Household member belongs to a farmer group (1/0)	0.87 (0.34)	0.89** (0.31)	0.84 (0.36)	0.90 (0.30)	0.88 (0.32)
Risk attitude	Risk attitude of household (1–10)[e]	5.58 (2.96)	5.81** (3.03)	5.33 (2.86)	6.13** (3.03)	5.47 (2.99)
Seasonal rainfall	Total rainfall during the last cropping season (mm)	891.23 (306.11)	907.22 (292.56)	858.27 (314.80)	907.82 (292.92)	906.54 (292.71)
WTP	Amount household is willing to pay per visit to plant clinic (ZMW)[f]	29.28 (32.34)	32.46*** (36.68)	25.68 (26.19)	37.10*** (45.15)	27.61 (24.09)
AEZ I	Household is located in agro-ecological zone I	0.17	0.13	0.23	0.14	0.11
AEZ IIa	Household is located in agro-ecological zone IIa	0.44	0.45	0.41	0.43	0.48
AEZ III	Household is located in agro-ecological zone III	0.39	0.42	0.36	0.44	0.41
No. of observations	Number of observations	837	444	393	227	217

Notes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.
[a] Plant clinic users are compared with non-users.
[b] Male clinic users are compared with female clinic users.
[c] Measured by the ratio of household members aged below 15 and above 64 to those aged 15–64.
[d] The asset index is based on household ownership of 11 durable assets. It was constructed using principal component analysis, following Filmer and Pritchett (2001).
[e] This is a survey-based risk preference measure, ranging from 0 (not at all willing to take risks) to 10 (fully prepared to take risks (Dohmen et al., 2011).
[f] At the time of the survey, 1 USD = 13 ZMW.

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, 2016b). 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 computed an indicator of severe food insecurity that is equal to one if a household's raw FIES score is 7 or 8; and zero otherwise.

4. Results and discussions

In this section, we first present the descriptive statistics of the explanatory and outcome variables, followed by the results of the impact of plant clinic participation, regardless of the gender of the participant. Finally, we present the results of the heterogeneous effects of plant clinics across gender.

4.1. Descriptive statistics

Table 1 reports the summary statistics of household characteristics, disaggregated by plant clinic participation status and gender. The average household in our sample is fairly large, with about seven members. Two thirds of the households are male-headed. The average household head is middle-aged with only eight years of education attainment. When assessed for risk attitudes, the typical household is fairly risk-neutral. Majority of the households are members of farmer associations; almost a quarter of them are credit constrained; and nearly half of them are engaged in off-farm work. When compared to non-clinic users, clinic user households own large farms and more livestock, and are more involved in farmer associations. On the other hand, non-clinic users live in closer proximity to agro-input markets than clinic users.

Among the plant clinic users, male clinic users have slightly better educated household heads, cultivate larger plot areas, and own more household durables and agricultural assets than female clinic users. Hence, it is not surprising that male clinic users are willing to pay a higher amount for plant clinic services than their female counterparts. Almost all the male clinic users are headed by males. Nearly half of the female clinic users are female heads, while the other half are wives in male-headed households. Our data show that 93% of the female-headed households are *de jure* female heads (i.e., single, widowed, divorced or separated) and the other 7% are de facto female heads (i.e., husband has migrated for work or is ill). Female clinic users have a lower risk-taking propensity than male clinic users, and this is consistent with evidence that women tend to be more risk averse than men (Eckel & Grossman, 2008).

Table 2
Summary statistics of plot-level variables.

Variable	Full sample	Clinic users[b]	Non-users	Male users[c]	Female users
Male owned (1/0)	0.39	0.41	0.37	0.61***	0.18
Female owned (1/0)	0.27	0.22***	0.34	0.04***	0.43
Jointly owned (1/0)	0.25	0.28***	0.20	0.28	0.29
Male managed (1/0)	0.34	0.35	0.31	0.51***	0.17
Female managed (1/0)	0.30	0.25***	0.37	0.02***	0.51
Jointly managed (1/0)	0.36	0.40***	0.32	0.47***	0.32
Plot size (hectares)	1.39	1.42	1.35	1.61**	1.19
	(1.77)	(2.03)	(1.38)	(2.59)	(1.01)
Plot distance to home (km)	1.77	1.74	1.81	1.63	1.87
	(3.87)	(3.57)	(4.21)	(3.67)	(3.46)
Sloped plot (1/0)	0.47	0.46	0.48	0.44	0.48
Fertile plot (1/0)[a]	0.33	0.36**	0.30	0.42***	0.29
Intercropped (1/0)	0.46	0.43**	0.49	0.44	0.43
Use of improved seed (1/0)	0.90	0.89	0.90	0.91	0.87
Use of inorganic fertilizer (1/0)	0.94	0.93	0.94	0.95*	0.91
Use of manure (1/0)	0.19	0.21	0.17	0.23	0.19
Use of herbicide (1/0)	0.37	0.39	0.35	0.46***	0.30
Use of insecticide (1/0)	0.55	0.66***	0.40	0.71**	0.62
Use of irrigation (1/0)	0.03	0.03	0.02	0.04	0.02
Use of hired labour (1/0)	0.41	0.40	0.41	0.45**	0.35
No. of observations	1048	576	472	307	269

Notes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.
[a] Farmers' perception of quality of plot.
[b] Plant clinic users are compared with non-users.
[c] Male clinic users are compared with female clinic users.

The summary statistics for the plot-level variables are presented in Table 2. A quarter of the plots are jointly owned by male and females, and roughly two-thirds of the plots are jointly managed. There are more male-owned and male-managed plots than female-own and female-managed plots in our sample.[5] The average maize plot size is <1.5 ha, and only one-third of the plots are perceived to be fertile. There is high use of improved seeds and inorganic fertilizers, but low use of manure and irrigation on the plots. When comparing male and female clinic users, we find that male users cultivate significantly larger plots, and their plots are significantly more fertile and benefits from inputs such as fertilizer, herbicide, insecticide and hired labour than female clinic users. We see a similar pattern of significant differences in plot size and quality, and input use when we compare male- and female-managed plots in Table A1 in the appendix. This supports the widespread belief and evidence that women have limited access to productivity-enhancing inputs compared to men (FAO, 2011, 2018; Quisumbing & Pandolfelli, 2010; O'Sullivan et al., 2014).

The summary statistics of the outcome indicators are presented in Table 3. The upper panel reports the plot-level outcomes. On average, farmers adopt a combination of three different FAW management practices. Consistent with recent studies in Zambia (Kansiime et al., 2019; Tambo, Day, et al., 2020), we see that the most commonly used FAW management method is chemical control. The average maize yield is about 1.5 tonnes/ha, which is slightly above the reported national average of about 1.3 tonnes/ha for the 2018/2019 cropping season (MoA, 2019). This is however lower than the yield values reported in recent previous cropping seasons, ranging from 1.7 tonnes/ha to 3 tonnes/ha (MoA, 2019; FAOSTAT, 2018). Besides FAW damages, a key driver of the decline in maize yield was rainfall deficits in parts of the country (MoA, 2019; FAO, 2020). The results show significant differences between clinic and non-clinic users in terms of adoption of direct control options such as mechanical and chemical methods but not in terms of regular monitoring and cultural control. We also find that clinic users obtained almost 300 kg/ha more maize yield than non-clinic users, and this translated into significant income difference of 940 ZMW/ha. Among the clinic users, significantly more male clinic users adopt mechanical and chemical controls than female users. There are no significant differences regarding the productivity outcomes, but plots controlled by female clinic users are less productive than those managed by male clinic users.

Turning to the food security outcomes in the lower panel of Table 3, we observe an average FIES (food insecurity) score of 4.64, indicating that a typical household in our data is moderately food insecure. Furthermore, 37% of the households are severely food insecure, and the reported average duration of inadequate household food provisioning is about three months. Maize is Zambia's main food staple; hence, the decline in maize production worsened the food insecurity situations in the country, particularly among agricultural households (FAO, 2020). Results also indicate that plant clinic users had significantly lower food insecurity scores than non-clinic users. Finally, households of male clinic users were found to be better food secure and to have experienced a significantly shorter hungry season than households of female clinic users.

4.2. Impact of plant clinic participation

Before presenting the results of the treatment effects of plant clinic participation, we first check if the overlap and covariate balancing conditions of the treatment models are fulfilled. The balance diagnostic test results in Table A2 in the appendix show insignificant chi-squared statistics; therefore, we can accept the null hypothesis that our treatment models balance the covariates by weighting (Imai & Ratkovic, 2014). Fig. A1 in the appendix shows sufficient overlaps in the distribution of the propensity scores between various clinic-user categories and non-clinic users, confirming a satisfaction of the overlap or common support condition. This indicates that given the covariates, each household has a positive probability of participating in plant clinics. The results from the balancing and overlap diagnostics suggest high degrees of comparability between our clinic-user categories and non-users after weighting; hence, we can now look at the results of the estimated treatment effects.

[5] Gender of plot manager refers to who makes the major decisions such as crops to be grown, input use and timing of cropping activities on the plot.

Table 3
Descriptive statistics of outcome variables.

Outcome variables	Full sample	Clinic users[b]	Non-users	Male users[c]	Female users
Plot-level outcomes					
Regular monitoring (1/0)	0.44	0.45	0.43	0.47	0.43
Cultural control (1/0)	0.54	0.53	0.55	0.55	0.50
Mechanical control (1/0)	0.48	0.51**	0.45	0.55*	0.47
Chemical control (1/0)	0.56	0.70***	0.41	0.75***	0.64
Adoption of FAW mgt practices (#)[a]	3.39	3.58**	3.17	3.77*	3.37
Maize yield (kg/ha)	1547.60	1682.43***	1383.52	1797.70	1550.74
Net maize income (ZMW/ha)	2575.52	2999.85***	2059.11	3171.12	2804.21
No. of observations	1048	576	472	307	269
Household-level outcomes					
Food insecure (0–8)	4.64	4.19***	5.15	3.81***	4.60
Severely food insecure (1/0)	0.37	0.31***	0.44	0.28	0.34
Food gap (months)	2.88	2.44***	3.37	2.23**	2.66
No. of observations	837	444	393	227	217

Notes: *** p < 0.01; ** p < 0.05; * p < 0.1.
[a] Adoption of FAW mgt practices (#) = the number of FAW management practices adopted on a plot.
[b] Plant clinic users are compared with non-users.
[c] Male clinic users are compared with female clinic users.

Table 4
Effects of plant clinic participation.

	Plant clinic users vs. non-users					
	Model 1			Model 2		
	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %
Regular monitoring (1/0)	0.03	0.03	6.98	0.03	0.03	6.98
Cultural control (1/0)	−0.01	0.03	−1.82	−0.02	0.03	−3.64
Mechanical control (1/0)	0.08**	0.03	18.18	0.07**	0.03	15.56
Chemical control (1/0)	0.33***	0.03	91.67	0.33***	0.03	89.19
Adoption of FAW mgt practices (#)	0.49**	0.20	15.81	0.48**	0.20	15.48
Maize yield (kg/ha)	211.36**	96.78	14.39	208.46**	97.32	14.14
Net maize income (ZMW/ha)	645.17***	245.21	27.40	638.61***	247.79	27.05
Food insecure (0–8)	−0.77***	0.21	−15.48	−0.71***	0.21	−14.48
Severely food insecure (1/0)	−0.10***	0.03	−25.31	−0.10***	0.03	−23.68
Food gap (months)	−0.63***	0.17	−20.56	−0.62***	0.17	−20.24

Notes: Model 1 omits the WTP variable, while Model 2 includes control for the WTP variable. *** p < 0.01; ** p < 0.05; * p < 0.1.

Table 4 reports the results of the doubly robust estimates of the impact of plant clinic participation, irrespective of the gender of the participant. Model 1 shows the results under weak unconfoundedness assumption (without controlling for WTP), while model 2 includes controls for WTP in attempts to attenuate bias stemming from unobservables. We find qualitatively similar results on all the outcome variables across the two models. In most cases, the magnitudes of the ATTs are slightly (0.5–2 percentage points) lower in the case of model 2 in which WTP is controlled for. Consequently, the discussion in this section will focus on model 2, but for comparison purposes, we also report the results for model 1 for all our estimates (see Tables A3–A5 in the appendix).

Results show that participation in plant clinics does not significantly increase the uptake of FAW preventive measures, such as regular monitoring and cultural controls. On the contrary, plant clinic users are about 16% and 90% significantly more likely to adopt mechanical and chemical control methods of FAW management, respectively. Farmers take diseased plants to the plant clinics; hence, its logical that plant doctors would be more likely to prescribe curative (i.e., mechanical and chemical) rather than preventive measures as an immediate solution. We find that clinic users have a 15% higher likelihood of adopting multiple FAW management techniques. This is a positive finding, given that IPM, which entails a combination of control methods, is recommended as the ideal method of FAW management (Day et al., 2017), and plant doctors are trained to advise farmers to adopt IPM strategies.

We also observe positive and significant yield effects of plant clinic participation. In particular, clinic users obtained 208 kg/ha or 14% yield gains relative to non-clinic users. Similarly, seeking plant health advice from plant clinics is significantly associated with a 27% increase in net maize income. Taken together, these results demonstrate that the positive impacts of plant clinics on technology adoption and crop yield reported by previous studies in other geographical regions like Bolivia (Bentley et al., 2011), Kenya (AIR, 2019) and Rwanda (Silvestri et al., 2019; Tambo, Uzayisenga, et al., 2020) are externally valid in the context of Zambia, even after controlling for plot-level heterogeneity.

Table 4 also shows that participation in plant clinics significantly contributes to a reduction in household food insecurity, especially severe food insecurity. We find that relative to non-clinic users, households that use plant clinic services are 14% and 24% less likely to be food insecure and severely food insecure, respectively, as measured by the FIES. Likewise, participation in plant clinics is associated with a 19-day reduction in the reported duration of household food insufficiency.[6] These are important results considering that the number of people facing severe acute food insecurity in Zambia during the study period is estimated to have more than doubled to 2.3 million compared with the same per-

[6] Given that a month contains about 30 days, an ATT of 0.62 months = 0.62 × 30 days per month = 18.6 days.

Table 5
Gender-differentiated effects of plant clinic participation.

	Male clinic users			Female clinic users		
	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %
Regular monitoring (1/0)	0.01	0.04	2.94	0.03	0.04	8.09
Cultural control (1/0)	−0.03	0.04	−4.68	−0.02	0.04	−3.45
Mechanical control (1/0)	0.14***	0.04	33.66	−0.01	0.04	−2.43
Chemical control (1/0)	0.39***	0.04	109.57	0.26***	0.04	68.52
Adoption of FAW mgt practices (#)	0.57**	0.29	17.96	0.38**	0.19	12.61
Maize yield (kg/ha)	271.58**	124.50	17.80	121.13	128.24	8.47
Net maize income (ZMW/ha)	704.17**	306.08	28.54	544.17	341.34	24.08
Food insecure (0–8)	−0.88***	0.28	−18.70	−0.57**	0.23	−10.99
Severely food insecure (1/0)	−0.10**	0.05	−25.79	−0.10**	0.04	−22.94
Food gap (months)	−0.55**	0.22	−19.91	−0.72***	0.20	−21.24

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Comparison group is non-clinic users.

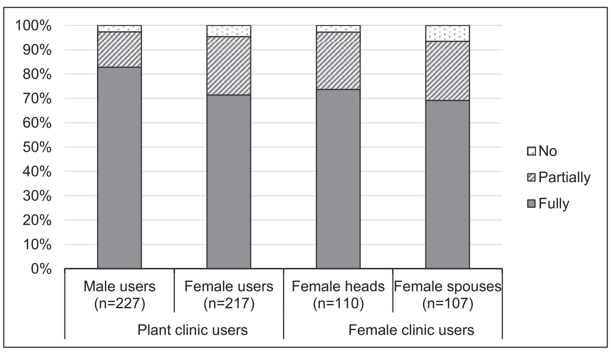

Fig. 2. Implementation of advice received at plant clinics.

iod the previous year, and this is largely due to crop production declines (FAO, 2020).

4.3. Treatment heterogeneity

Having shown above that plant clinic users outperform non-clinic users on our key outcomes of interest, we now present the estimation results on whether the gender of the clinic user matters. In Table 5, we compare male clinic users with non-clinic users as well as female clinic users with non-clinic users. We find considerable heterogeneity in the effectiveness of plant clinics across gender groups. First, while male clinic users have a 34% higher likelihood of adopting mechanical control than non-clinic users, there are no significant effects between female clinic users and non-users. Mechanical controls such as handpicking and crushing of larvae and rogueing of infested plants are labour-intensive control methods; hence, it may be less attractive to female clinic users who may lack men's household labour or the capital to hire labour (as shown in Table 2) to implement this control option. Second, male and female clinic users are respectively about 110% and 69% significantly more likely to adopt chemical control than non-clinic users. Similarly, relative to non-clinic users, male and female clinic users have 18% and 13% higher probability of adopting multiple FAW management options. Thus, compared to a similar control group, male clinic users are more likely to adopt multiple and capital-intensive control options than female clinic users, pointing to gender inequalities in access to productive resources. In fact, our data show that relatively more male clinic users than female clinic users self-reported being able to fully implement the plant health advice received at the clinics (Fig. 2).

Third, looking at the productivity outcomes, we find that male clinic users achieve significant maize yield and income increases of nearly 18% and 29% respectively compared to non-clinic users. On the other hand, although female clinic users outperformed non-clinic users on these two outcomes, the ATT estimates are not statistically significant. This implies that the significant effect of plant clinics on maize productivity reported earlier in Section 4.2 is largely driven by male clinic participation. This resonates with evidence from Ethiopia and Uganda showing that women benefit less than men from some extension services, in terms of increased agricultural productivity (O'Sullivan et al., 2014).

Fourth, participation in plant clinics improves food security for both male and female clinic users. However, the positive food and severe food insecurity reduction effects of plant clinics are slightly greater for male clinic users. On the other hand, relative to non-clinic users, female users benefit more in terms of the shortening of the days seasonal hungry season (about 22 days and 17 days for female and male clinic users, respectively). Thus, the differential gendered effects of plant clinics on food security depend on the food security indicator employed. One may note that although

Table 6
Differential effects of female clinic participation.

	Female heads			Female spouses		
	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %
Regular monitoring (1/0)	0.09	0.06	23.34	−0.01	0.05	−3.25
Cultural control (1/0)	0.05	0.06	10.42	−0.08	0.05	−14.38
Mechanical control (1/0)	−0.11*	0.06	−20.74	0.07	0.05	17.36
Chemical control (1/0)	0.31***	0.05	82.31	0.22***	0.05	58.53
Adoption of FAW mgt practices (#)	0.49*	0.27	16.44	0.32	0.24	10.99
Maize yield (kg/ha)	275.65	187.25	21.09	38.89	160.13	2.62
Net maize income (ZMW/ha)	827.13	510.06	41.07	383.10	408.16	16.03
Food insecure (0–8)	−0.83***	0.29	−15.09	−0.33	0.31	−6.78
Severely food insecure (1/0)	−0.10*	0.05	−20.41	−0.11**	0.05	−27.50
Food gap (months)	−0.81***	0.26	−22.50	−0.65**	0.29	−20.50

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Comparison group is non-clinic users.

Table 7
Plot-level gender-differentiated effects of clinic participation.

	Male clinic users						Female clinic users					
	Male-managed plots			Jointly-managed plots			Female-managed plots			Jointly-managed plots		
	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %
Regular monitoring (1/0)	−0.01	0.06	−2.13	0.00	0.07	0.21	0.04	0.06	9.52	−0.04	0.08	9.52
Cultural control (1/0)	−0.02	0.06	−3.70	−0.06	0.05	−9.09	−0.08	0.06	−14.29	−0.01	0.50	−1.20
Mechanical control (1/0)	0.19***	0.07	55.88	0.08	0.06	16.00	−0.04	0.06	−7.55	−0.02	0.08	−4.26
Chemical control (1/0)	0.34***	0.06	101.78	0.43***	0.06	104.93	0.22***	0.06	52.38	0.34***	0.08	103.40
Adoption of FAW mgt practices (#)	0.66**	0.28	23.83	−0.68	1.61	−14.20	0.21	0.28	6.75	0.55	0.38	18.84

Note: *** p < 0.01; ** p < 0.05; * p < 0.1.

female participation does not significantly increase productivity, it results in improved food security. A plausible explanation is that the small positive maize yield and income effects of female participation in clinics helped cushion short-term food shortages, given that we used transitory measures of food insecurity. Another potential reason is that the knowledge gained from clinic participation generates positive spillovers to other crops besides maize, and their combined effects are reflected in broader outcomes such as food security.

In Table 6, we explore another gender dimension by disaggregating the female clinic users into female heads of households (female heads) and wives in male-headed households (female spouses) and compare them with non-clinic users. Results show that both categories of female clinic users are significantly more likely to use chemical method of FAW control compared to non-clinic users, but the effect is more pronounced for female heads. In terms of adoption of multiple FAW management practices, the effect is statistically significant (albeit marginally) only for female heads. Participation in plant clinics is also significantly and negatively related to the three food insecurity indicators for both female heads and spouses, except the food insecure outcome, which is not statistically significant in the case of female spouses. Although not statistically significant, the positive productivity effects of clinic participation are disproportionately greater for female heads.

Taken together, these results suggest that while female participation in plant clinics generate some positive outcomes, households in which the female participant is the head of household benefit more than households in which the female participant is a spouse. A possible explanation is that female heads may have more decision-making authority than female spouses to directly implement plant doctors' recommendations. As shown in Fig. 2, proportionally more female spouses than female heads indicated that they were not able to implement any of the FAW management practices recommended by plant doctors. In a recent study in a neighbouring country (Malawi), Ragasa et al., (2019) observed that some men doubted the ability of their spouses to comprehend extension messages. This could constitute an obstacle to the application of knowledge gained from plant clinics by female spouses.

Finally, we test whether participation in plant clinics stimulates the adoption of FAW management practices on all or certain household plots. First, we examine whether male participation influences technology adoption on both male- and jointly-managed plots, and secondly whether female participation impacts technology adoption on both female- or jointly managed plots. Unfortunately, due to limited observations, we are not able to estimate the effect of male (female) participation on technology adoption on female (male)-managed plots, which would have been interesting.

The results in Table 7 indicate that male participation in plant clinics significantly enhances the likelihood of adoption of mechanical methods of FAW control on both male- and jointly managed plots. However, the effect size for male-managed plots is about twice that for jointly managed plots. Likewise, male participation increases the probability of using chemical control on both male- and jointly-managed plots, and the ATT estimates are roughly similar in magnitude. On the other hand, male participation exerts a significant effect on the uptake of multiple FAW management practices on only male-managed plots. Taken together, these results point to plot-level gender inequalities in the application of knowledge gained from male participation in plant clinics.

Turning to the results for female participation, we find statistically significant effects on only the adoption of chemical control. Noteworthy is the difference in the magnitude of the ATT estimates. The likelihood of female participation in plant clinics resulting in the use of chemical pesticides on jointly managed plots is double that on female-manage plots. Once again, this reflects the issue of gender disparities in access to resources, given that the female-managed plots are largely owned by female-heads while the jointly-managed plots are owned by male heads, either independently or jointly with their spouses (see Table A1 in the appendix)

5. Conclusion

In this paper, we presented evidence on the gender-differentiated impacts of plant clinics, a demand-driven extension approach that aims to help smallholder farmers tackle pest problems through the provision of diagnostic services and actionable crop health information. Using gender-disaggregated data from 837 smallholder households cultivating 1048 maize plots in rural Zambia, we examined whether male and female farmers accrue similar benefits, in terms of adoption of crop protection technologies, increased maize productivity and improved food security, from participating in plant clinics. We contribute to the literature on the effectiveness of agricultural extension programmes in bridging the gender technology and productivity gaps in agriculture. Our findings are also relevant from a policy perspective, especially given the increasing threats from new invasive pests such as fall armyworm, and global efforts towards achieving gender equality and food security, as emphasised in the SDGs.

Consistent with previous studies (Bentley et al., 2011; Silvestri et al., 2019; Tambo, Uzayisenga, et al., 2020), we found positive impacts of plant clinics on technology adoption and crop productivity, even after controlling for plot-level differences (which was not the case in previous studies) along with household and contextual factors. Our evidence shows that participation in plant clinics encourages the adoption of multiple pest management techniques, resulting in significant maize yield and income gains of 14% and 27%, respectively. Additionally, using plant clinic services is significantly associated with reductions in the duration of food scarcity and severe food insecurity, as measured by the Food Insecurity Experience Scale (FIES).

Gender disaggregated analysis shows that while both male and female farmers achieve positive gains from participating in plant clinics, the gains are more pronounced for male participants. For instance, our treatment effect estimates indicate that male clinic users achieve maize yield increases of about 18% compared to 8% for female clinic users, and even the estimate is only statistically significant for male clinic users. Estimation results suggest that this is partly because male clinic users have a higher likelihood of adopting multiple and capital-intensive pest control options, reflecting gender disparities in access to productive resources. The results further indicate that among the female participants, the benefits from using plant clinic services are disproportionately larger for female heads than for female spouses, signifying the advantage of women's intra-household decision-making power. Finally, we found some evidence pointing to inequalities in the probability of application of knowledge gained from male participation in plant clinics to male- versus jointly-managed plots.

In summary, our findings imply that providing smallholders with plant health diagnostic and advisory services via plant clinics is worthwhile in terms of improved management of crop pests, increased productivity and achieving household food security. Participating in plant clinics allows both male and female farmers to significantly increase the adoption of crop protection techniques, but this is not sufficient to overcome the gender disparity in agricultural productivity. While there are increasing efforts to encourage female participation in plant clinics (CABI, 2019), maximizing the effectiveness of plant clinics for female participants would require providing them with additional support to implement the knowledge gained as well as addressing underlying gender inequalities and power relations. Moreover, any policy support to exploit the economic benefits of female participation should consider the differential implications for female household heads and females in male-headed households.

Finally, a few limitations of our study should be acknowledged. First, this study is based on cross-sectional data, which preclude the analysis of the dynamics and long-term impacts of plant clinics. For instance, we found significant evidence of an association between plant clinic participation and the use of direct pest control measures, such as chemical control, but not the use of long-term pest prevention strategies, such as cultural control. It would be interesting to find out if clinic users put the knowledge gained on prevention methods into practice in subsequent cropping seasons, as these methods are central to the promotion of sustainable pest management. This may also have gender implications, given the evidence that female farmers with access to extension are more likely to adopt agricultural practices that require low upfront monetary investment, including intercropping and crop rotation (Pan et al., 2018). Such analyses will require panel data, which at the same time can better account for unobserved heterogeneity. Another area of future research is to examine if there are synergistic effects of joint male and female participation relative to individual participation in plant clinics. This was not possible in the current study because our sample did not include joint participation in plant clinics. Some previous studies have shown that joint participation of male and female household members in agricultural extension services achieve the highest outcome (Lambrecht et al., 2016; Ragasa et al., 2019).

CRediT authorship contribution statement

Justice A. Tambo: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration. **Mathews Matimelo:** Data curation, Investigation. **Fredrick Mbugua:** Data curation, Software. **Mathias Ndhlovu:** Data curation, Investigation, Writing - review & editing. **Noah Phiri:** Writing - review & editing, Project administration.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Justice A. Tambo, Frederick Mbugua and Noah Phiri are employed at CABI, the institution that manages the Plantwise programme.

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Appendix A

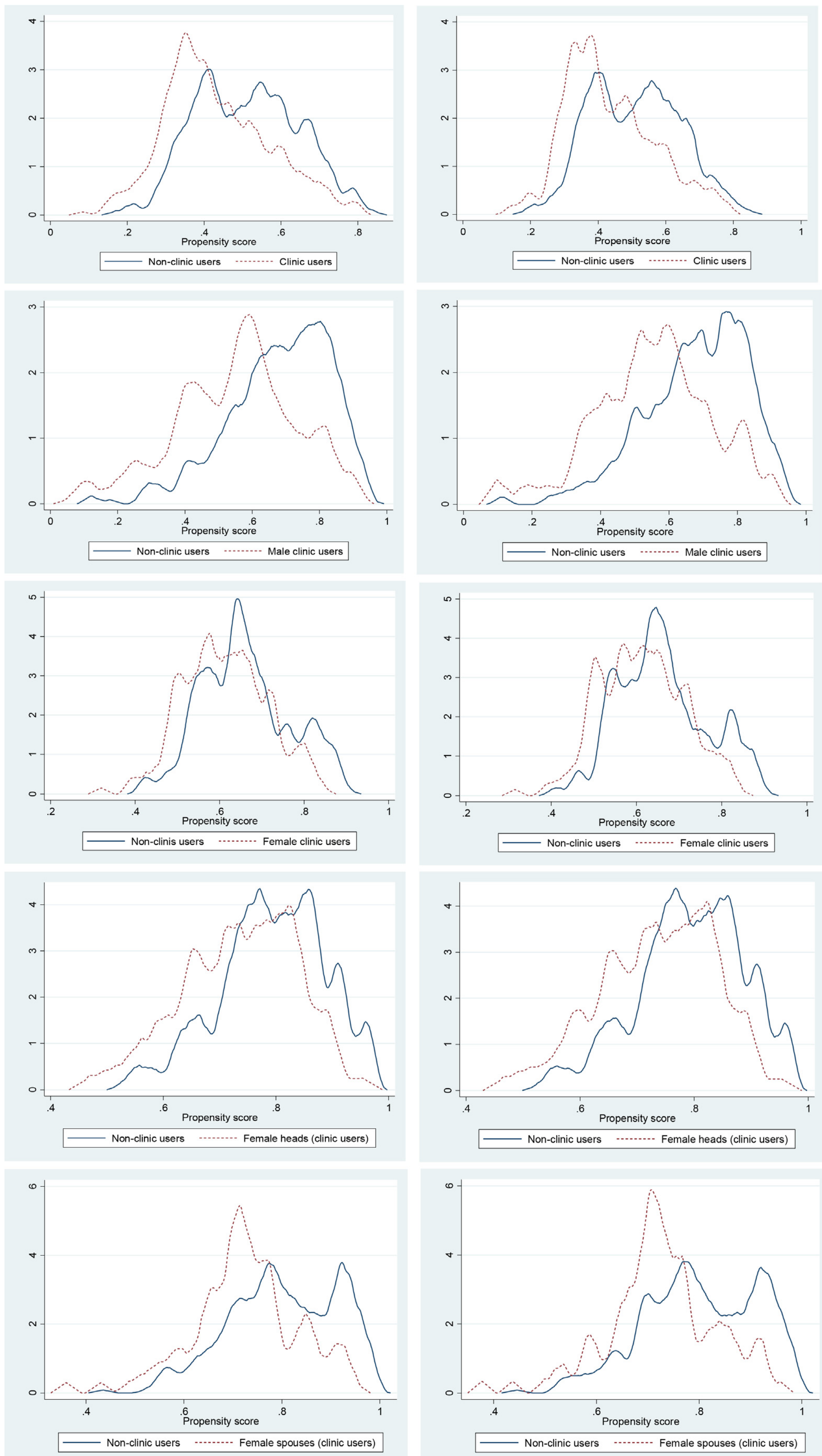

Fig. A1. Kernel density distribution showing overlap between clinic and non-clinic users. The left panels include controls for WTP, while the right panels do not.

Table A1
Plot-level gender-disaggregated characteristics.

	Male managed	Female managed	Jointly managed
Male owned (1/0)	0.72	0.06***	0.37***
Female owned (1/0)	0.03	0.79***	0.06*
Jointly owned (1/0)	0.15	0.07***	0.49***
Plot size (ha)	1.51	1.02***	1.58
	(1.47)	(0.86)	(2.42)
Plot distance (km)	1.81	1.92	1.62
	(4.60)	(3.39)	(3.49)
Sloped plot (1/0)	0.45	0.48	0.47
Fertile plot (1/0)	0.34	0.26**	0.39
Use of improved seed (1/0)	0.90	0.89	0.91
Use of inorganic fertilizer (1/0)	0.95	0.91*	0.96
Use of manure (1/0)	0.16	0.18	0.23**
Use of herbicide (1/0)	0.37	0.31*	0.43
Use of insecticide (1/0)	0.54	0.48	0.61*
Use of hired labour (1/0)	0.43	0.35**	0.44
Regular monitoring (1/0)	0.45	0.42	0.45
Cultural control (1/0)	0.53	0.50	0.57
Mechanical control (1/0)	0.44	0.50	0.52**
Chemical control (1/0)	0.55	0.49	0.63**
Adoption of FAW mgt practices (#)	3.22	3.11	3.78***
Maize yield (kg/ha)	1634.74	1399.95*	1591.54
Net maize income (ZMW/ha)	2695.73	2135.65	2833.69
No. of observations	350	318	380

Note: Female and jointly managed plots are compared with male managed plots.
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table A2
Tests of covariate balancing.

Treatment model	Omitting WTP		Including WTP	
	Chi^2	*p*-value	*Chi*^{2}	*p*-value
Clinic users vs. non-users	24.53	0.1058	24.64	0.135
Male clinic users vs. non-users	18.24	0.3741	17.08	0.518
Female clinic users vs. non-users	15.27	0.5758	13.92	0.735
Female heads vs. non-users	8.09	0.9461	8.73	0.958
Female spouses vs. non-users	9.92	0.8707	9.49	0.924

Table A3
Gender-differentiated effects of plant clinic participation (without WTP).

	Male clinic users			Female clinic users		
	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %
Regular monitoring (1/0)	0.01	0.04	2.35	0.03	0.04	8.31
Cultural control (1/0)	−0.02	0.04	−4.07	−0.02	0.04	−3.30
Mechanical control (1/0)	0.15***	0.04	37.12	−0.01	0.04	−1.57
Chemical control (1/0)	0.39***	0.04	111.22	0.26***	0.04	68.99
Adoption of FAW mgt practices (#)	0.57*	0.31	17.78	0.38**	0.19	12.73
Maize yield (kg/ha)	274.96**	123.49	18.06	121.25	128.10	8.48
Net maize income (ZMW/ha)	704.17**	306.08	28.54	539.28	339.55	23.81
Food insecure (0–8)	−0.98***	0.28	−20.47	−0.58**	0.23	−11.26
Severely food insecure (1/0)	−0.11**	0.05	−28.14	−0.10***	0.04	−23.48
Food gap (months)	−0.58***	0.22	−20.57	−0.72***	0.20	−21.29

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Comparison group is non-clinic users.

Table A4
Differential effects of female participation in plant clinics (without WTP).

	Female heads			Female spouses		
	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %
Regular monitoring (1/0)	0.09	0.06	23.46	−0.01	0.05	−3.23
Cultural control (1/0)	0.05	0.06	10.40	−0.07	0.05	−14.07
Mechanical control (1/0)	−0.11**	0.06	−20.64	0.08	0.05	19.42
Chemical control (1/0)	0.31***	0.05	82.39	0.22***	0.05	59.19
Adoption of FAW mgt practices (#)	0.50*	0.27	16.58	0.33	0.24	11.19
Maize yield (kg/ha)	275.05	186.91	21.04	43.71	160.09	2.95
Net maize income (ZMW/ha)	823.09	508.62	40.78	396.24	407.54	16.67
Food insecure (0–8)	−0.84***	0.29	−15.27	−0.36	0.31	−7.36
Severely food insecure (1/0)	−0.10*	0.05	−20.41	−0.11**	0.05	−27.50
Food gap (months)	−0.81***	0.26	−22.50	−0.66**	0.29	−20.75

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Comparison group is non-clinic users.

Table A5
Plot-level gender-differentiated effects of clinic participation (without WTP).

	Male clinic users						Female clinic users					
	Male-managed plots			Jointly-managed plots			Female-managed plots			Jointly-managed plots		
	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %	ATT	Robust SE	ATT in %
Regular monitoring (1/0)	−0.01	0.06	−2.13	0.00	0.07	0.21	0.05	0.06	12.20	−0.04	0.08	9.52
Cultural control (1/0)	−0.02	0.06	−3.70	−0.05	0.06	−7.69	−0.07	0.06	−12.50	−0.01	0.07	−2.00
Mechanical control (1/0)	0.19***	0.06	55.88	0.11*	0.06	23.40	−0.04	0.06	−7.55	−0.02	0.08	4.26
Chemical control (1/0)	0.35***	0.06	103.59	0.41***	0.06	98.10	0.22***	0.06	52.38	0.33***	0.08	103.13
Adoption of FAW mgt practices (#)	0.67**	0.28	24.19	−0.29	1.18	−6.58	0.21	0.28	6.77	0.55	0.38	18.84

Note: *** p < 0.01; ** p < 0.05; * p < 0.1.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.worlddev.2021.105519.

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