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ORIGINAL PAPER

Pest risk information, agricultural outcomes and food security: evidence from Ghana

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Abstract

This article investigates the short-term effects of an information intervention that provided early warning pest alerts and integrated pest management (IPM)-based advice to smallholder farmers. Specifically, this study focuses on fall armyworm (*Spodoptera frugiperda*) of maize in Ghana. We particularly examine the relationships between access to pest risk information and a number of outcomes, ranging from farmer's knowledge to household food security. This study is based on survey data collected between December 2021 and January 2022 from 888 farm households operating 1305 maize fields. Results from doubly robust and switching regression models indicated that exposure to the pest risk information campaign was significantly $(\rho < 0.05)$ associated with increases in the likelihood of optimal timing of fall armyworm control action and the adoption of multiple IPM practices, but it had no significant effect on pesticide use. Households who received the pest risk information obtained an average of 4% or 54 kg/ha $(\rho < 0.01)$ gain in maize yield and were about 38% less likely $(\rho < 0.01)$ than their non-recipient counterparts to report experiencing hunger, as measured by the household hunger scale. However, the pest risk information campaign was not associated with greater household dietary diversity. Further results indicated that households where the pest risk information was received by women, alone or together with their spouses, were more likely $(\rho < 0.05)$ to achieve positive outcomes than if the recipient of information were male member of households. Overall, our findings imply that the dissemination of early warning pest alerts in combination with actionable IPM information to smallholder farmers can contribute to the adoption of sustainable crop protection technologies, and ultimately improve the standard of living of farm households.

Keywords Early Warning · Fall Armyworm · Integrated Pest Management · Agricultural Productivity · Food Security · Gender

1 Introduction

Crop pests (pathogens, weeds and animal pests, such as insects and mites) are associated with very large socio-economic and environmental costs (Pimental & Andow, 1984; Oerke, 2006; Savary et al., 2012, 2019). For instance, estimates of global yield losses caused by crop pests on five major food crops (maize, potato, rice, soybean and wheat) range between 17 and 30% (Savary et al., 2019). In Africa, the total annual cost of invasive animal, pathogen and weed species to agriculture is estimated to be USD 65.58 billion (Eschen et al., 2021). Unfortunately, outbreaks of animal pests of crops are increasing and becoming unpredictable due to factors such as increasing globalisation of trade, agricultural intensification, and climate change (Early et al., 2016; Prasanna et al.,

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2022; Wilby & Thomas, 2002). For example, fall armyworm (FAW), *Spodoptera frugiperda*, which originates from the Americas, has spread rapidly to over 80 countries across Africa, Asia, and Oceania within five years since it first invaded West Africa in 2016 (CABI, 2022). Empirical research has shown that the FAW outbreak in Africa is causing severe damage to maize crops, resulting in significant yield losses of about 26% in Ghana and 35% in Zambia (Rwomushana et al., 2018), 33% in Kenya (De Groote et al., 2020), and 36% in Ethiopia (Abro et al., 2021. The FAW invasion has also been associated with increased food insecurity in Ghana and Zimbabwe (Tambo et al., 2021a; Bannor et al., 2022), and increased use of pesticides in several African countries, with associated adverse human health and environmental consequences (Abro et al., 2021; Tambo et al., 2020).

These detrimental effects of crop pests highlight the need to increase farmers' resilience to pest outbreaks in order to achieve several of the sustainable development goals. Unfortunately, developing-country farmers often lack access to timely and early warning information on pest outbreaks and plant health problems (Cameron et al., 2016). Early warnings of pest outbreak risks are crucial to prevent pest population build-up, optimise pest control and reduce crop losses (Prasad & Prabhakar, 2012; Brown et al., 2022). Moreover, integrated pest management (IPM), which involves the use of a variety of sustainable pest control techniques, including biological, cultural, genetic and physical practices, as well as chemical methods as a last resort, is not widely adopted in low-income countries, partly due to lack of information (Orr, 2003; Dhawan & Peshin, 2009; Parsa et al., 2014; Alwang et al., 2019). In an attempt to address these issues, CABI in collaboration with several international partners initiated the pest risk information service (PRISE) project with the goal of improving smallholder livelihoods by reducing pest-induced crop losses. More specifically, the project uses a novel combination of earth observation technology, satellite data, pest life-cycle, and real-time field observations, to deliver early warnings on crop pests to farmers, so that they can use appropriate management measures in good time to mitigate yield losses (Lowry et al., 2022). In Ghana, early warning FAW alerts and IPM information were disseminated to farmers during the 2021 agricultural season.

In this study, we assess the impact of a pest risk information intervention in Ghana on a number of agricultural and development outcomes. The study is based on survey data from 888 smallholder maize farmers and 1350 maize fields in two major maize-growing regions of Ghana, where maize is an important food security crop. In Ghana, maize is cultivated on about 1.3 million hectares, accounting for more than half of the country's cereal production, with an annual production of about 3.5 million tonnes (FAOSTAT, 2023; Wongnaa et al., 2019).

The research questions addressed in this study include: (1) Did the pest risk information campaign enhance farmers' pest knowledge and stimulate the adoption of recommended IPM practices? (2) Did the information campaign contribute to reduced yield losses and improved household welfare? and (3) Did male and female farmers equally benefit from the information campaign, or are there gender-differentiated impacts? By addressing these research questions, this study aims to contribute to the literature related to agricultural extension, IPM information dissemination and gender gap in agriculture.

Over the past few decades, IPM has been widely promoted in many developing countries using face-to-face extension approaches, particularly farmer field schools, with mixed results in terms of effectiveness (see Waddington et al., 2014; van den Berg et al., 2020 for reviews). Given the weaknesses of face-to-face extension (such as limited reach and high costs) (Anderson & Feder, 2007), coupled with the rapid spread of ICTs in developing countries (Aker, 2011), the use of mass media instruments to disseminate IPM information has also received considerable attention in the literature. For example, mass media channels, such as leaflets, posters, radio dramas and television features have been used to promote management strategies against rice pests in Vietnam and the Philippines in Asia (Escalada et al., 1999; Flor & Singleton, 2011; Heong et al., 1998; Rejesus et al., 2009). Similarly, mobile phone messages, radio and video and have been used, either in isolation or in combination, to improve farmer knowledge and stimulate the adoption of IPM practices against FAW on maize in Rwanda, Uganda and Zambia in Africa (Tambo et al., 2019, 2023a; Rware et al., 2021). We expand on the previous literature by investigating the impact of a unique mass media campaign that provided farmers with early warning information on FAW infestation and management. Moreover, unlike the previous studies, the mass media campaign assessed in this study relied heavily on community information centres (CICs), which are a popular communication channel in Ghana but have so far received no attention in the literature.

We analyse the impact of the mass media campaign on several outcomes, including farmer knowledge of FAW, adoption of IPM practices, pesticide use, maize yield and household food security. Existing studies tended to focus on only farm-level outcomes, especially farmer knowledge and technology adoption (e.g., Flor & Singleton, 2011; Heong et al., 1998; Larochelle et al., 2019; Rejesus et al., 2009; Tambo et al., 2019).) Here, we also examine impacts on broader development outcomes (food security), which can also capture potential indirect effects of the information campaign. Finally, by examining the heterogeneous effects of the pest risk information intervention on gender groups, our study complements the few empirical studies on the gendered impacts of agricultural extension and advisory services (Lambrecht et al., 2016; Ragasa et al., 2019; Tambo et al., 2021b).

The rest of the article is structured as follows. The next section provides a brief overview of the pest risk information intervention in Ghana, while section three describes the survey data and the empirical strategy. Following this, section four presents the study results, which are discussed in section five. Section six concludes with a summary of the main findings and their policy implications.

2 The fall army worm risk information campaign in Ghana

This study aims at evaluating the impact of a pest risk information intervention that was implemented in Ghana against fall army worm (FAW) during the 2021 maize cropping season by CABI in collaboration with the Plant Protection and Regulatory Services Directorate of Ghana through the PRISE project. As indicated earlier, PRISE used a combination of satellite observations, geographic and weather data, and pest modelling to forecast the risk of FAW outbreaks, which were then transmitted to farmers through two mass media channels: CICs and voice short message service (SMS).

Community information centres (CICs) are used to inform and sensitise residents of many rural and remote communities in Ghana. CICs provide several information services, including announcements, interviews, product marketing, event promotions, news and religious broadcasts, and emergency response calls. They usually operate from small shops, people's homes or temporary structures with a simple set-up, comprising a monitor, a microphone, a recorder, an amplifier, and two to four horn loudspeakers mounted on a pole of up to 10 m high. The information broadcasted by a CIC can travel up to 1 km from where it is located. In smaller communities, messages broadcasted by CICs reach all community members. CICs are either privately owned or established by an entire community and are usually operated by respected members of the community.

CICs have several advantages over other mass media channels, such as radio. First, they provide low-cost services, and are thus accessible to many users. For instance, the owners of CICs were each paid about USD 40 for a four-month broadcast of pest risk information. In addition, CICs offer mass audience coverage, even in areas with limited access to traditional media and mobile network. Moreover, by design, most community members are likely to be exposed to the messages broadcasted by CICs, whether of interest or not. In large communities, however, CIC messages may not reach distant households due to weak broadcast signals. In addition, due to excessive noise generated by some of CICs, some residents consider them to be public nuisance and choose not to listen or pay attention to the messages they disseminate. This has led to calls for Ghanaian authorities to regulate their operations, for instance, by formulating and enforcing by-laws on the contents of messages transmitted, the maximum permissible noise levels and the times of the day when they can operate (Nartey, 2019).

Based on the level of maize production, maize pest incidence and the availability of reliable CICs, 10 districts were selected across two administrative regions of Ghana (i.e., Bono and Bono East regions) for inclusion in the pest risk information intervention. In each district, 10 CICs were selected to participate in the information campaign, making a total of 100 CICs. The operators of these 100 CICs were then invited to a two-day workshop and trained on how to disseminate pest risk information. Jingles on IPM practices against FAW and maize stalk borer (MSB) pests were developed and given to all CICs to be aired daily at peak listening times (i.e., early mornings and late evenings) between June and September 2021. In addition, the CIC operators were sent early warning forecasts on these two pests every fortnight for timely dissemination to farmers. Plant health experts and agricultural extension agents also provided technical backstopping through periodic interviews at CICs to further explain some of the campaign topics.

To reinforce the campaign messages, Esoko (a digital service company in Ghana) was engaged to distribute voice SMS messages to about 10,000 maize farmers in the two project regions, whose mobile phone numbers they already had in their database. Unlike SMS text messages, which are commonly used in SMS-based information campaigns, voice SMS messages are more appropriate in low-literacy environments, as in our case. Each farmer received about 30 voice SMS messages over a period of four months spanning the maize-growing season. The voice SMS messages were similar to those disseminated by CICs, and included early warning pest alerts, signs and symptoms of FAW and MSB, recommended IPM practices, good agricultural practices, and rational use of pesticides. Campaign messages were broadcasted in *Akan*, the most-widely spoken language in the study area and in Ghana.

3 Data and methods

3.1 Data

This study is based on survey data collected from farm households in Bono and Bono East regions, which are major maize-producing regions of Ghana. Located in the middle-belt of the country (Fig. 1), these two regions are where the pest risk information intervention was implemented. Each region has a population of about 1.2 million people, and about 41% and 47% of the inhabitants respectively in Bono and Bono East regions live in rural areas (GSS, 2021).

Fig. 1 Map of Ghana showing the study locations

Smallholder farming is the main economic activity in the study regions, with about 62% of the households owning or operating a farm (GSS, 2019). Besides maize, the major crops cultivated in the regions include starchy staples, such as cassava, plantain and yam, as well as cash crops, such as cashew and cocoa.

Our sample households were selected from 10 districts where CICs were used to disseminate pest risk information to farmers. The districts include Berekum East, Dormaa East, Sunyani Municipal, Sunyani West, Tain and Wenchi in Bono region; and Kintampo South, Nkoranza North, Nkoranza South and Techiman North in the Bono East region. Each of these districts had 10 intervention communities, which are communities where CICs had been contracted to broadcast the pest risk information. In each district, we randomly selected five out of the 10 intervention communities. Given that a majority of households in the intervention communities were likely to have been exposed to the campaign messages disseminated by CICs, we also randomly selected three non-intervention communities per district, with support from local extension workers. The non-intervention communities also had CICs and were nearby to the intervention communities. However, CICs in the non-intervention communities were not involved in the pest risk information campaign. Within each community, 8–15 households were then randomly selected and interviewed by enumerators who were trained by the authors.

The enumerators used pre-tested tablet-based questionnaires, which contained modules on household demographic characteristics, exposure to the pest risk information campaign, a five-item pest knowledge test, maize production, adoption of IPM practices, access to institutional support services, household income, and food security. The data covered the 2021 main maize cropping season of Ghana and were collected between December 2021 and January 2022. Altogether, 888 maize-farming households operating 1035 maize fields were interviewed. The sample households comprise 377 and 511 recipients and non-recipients of the pest risk information, respectively. Among the 377 information recipients, 314, 13, and 50 of them received the campaign messages through CIC only, SMS only, and both CIC and SMS, respectively. 36% and 64% of the 511 information non-recipients lived within the intervention and non-intervention communities, respectively.

3.2 Empirical approach

Based on evidence from previous research (Larochelle et al., 2019; Silvestri et al., 2019; Tambo et al., 2019), it is expected that the pest information intervention will lead to an increase in farmers' pest knowledge and awareness of sustainable crop protection practices, which will then stimulate the adoption of IPM practices. We also hypothesise that the adoption of the IPM practices will lead to reduced yield losses to pests, and thus increased availability of self-produced food for household consumption or increased income that can be spent on food consumption and in improving household well-being. Hence, this article aims to estimate the effect of the pest risk information intervention on a number of outcome variables, ranging from farmers' pest knowledge to household food security. This can be expressed as:

$$y_i = \alpha_i + \omega z_i + \delta R_i + \varepsilon_i \quad (1)$$

where y_i represents the outcome indicators for field or household i. The outcome variables are presented in the next section. z_i denotes a vector of covariates, with their associated parameters ω; R_i is a dummy variable equal to one if household i is a recipient of the pest risk information and zero otherwise; and ε_i is a random error term. The coefficient of interest is δ, which measures the effect of the information intervention on the outcome variables.

An important concern when estimating Eq. (1) is that the receipt of pest risk information is not randomly assigned; hence, our treatment variable R is potentially endogenous to the outcome indicators y. Thus, it is possible that recipients and non-recipients of the pest risk information may differ systematically in observable and unobservable factors that could influence y, and failure to account for this may produce biased results. To reduce this possible bias, we apply the inverse-probability regression adjustment (IPWRA) method, which is a doubly robust estimator (Wooldridge, 2010).

In the IPWRA approach, a logit regression model is used to estimate the probability of a household receiving the pest risk information (i.e. treatment model), which can be specified as:

$$R_i = \beta x_i + \mu_i \quad (2)$$

where R_i is as defined in Eq. (1), ε_i is an error term, and x_i is a set of control variables that affect the receipt of pest risk information. Using inverse-probability weights obtained from the treatment model, weighted outcome models are fitted to obtain the predicted outcomes for the recipients and non-recipients of the pest risk information (outcome models). The outcome models are fitted using probit, linear and Poisson regression models for binary, continuous and count outcome variables, respectively (StataCorp, 2015). The predicted mean outcomes are then used to provide estimates of the average treatment effect on the treated (ATT), which measures the effects of the pest risk information intervention on the households who received the information. The IPWRA and all other analyses in this article were performed using Stata version 16.

Inspired by literature on the impacts of pest information interventions on agricultural outcomes (e.g., Rware et al., 2021; Silvestri et al., 2019; Tambo et al., 2019), the control variables (z_i and x_i) in Eqs. 1 and 2 include household demographic characteristics (e.g., age, educational attainment and gender of the head of household, and household size); household resource endowment (such as field size, livestock and durable asset holdings), a measure of risk reference, and institutional-related factors (e.g., farmer group membership and proximity to other information sources). We also include district dummies, which control for geographic differences, such as agro-climatic conditions and other unobserved heterogeneity across districts. For the field-level outcomes, the vector z_i also comprise field-level variables such as tenure security, perception of field quality, farm inputs use (seed, fertilizer, pesticide and hired labour). Table 1 provides a list and description of the control variables.

An important feature of the IPWRA method is its doubly robust property, meaning that if either the treatment model or outcome model is mis-specified, the ATT estimates would still be consistent (Imbens & Wooldridge, 2009). However, it should be emphasised that the doubly robust method is a selection-on-observable estimator; hence, it cannot control for potential bias stemming from unobserved heterogeneity. Hence, ATT estimates from the IPWRA approach should be interpreted as associations rather than causal relationships (Imbens, 2004). When using cross-sectional observational data, as in our case, one of the commonly used methods for addressing unobserved heterogeneity is the instrumental variable (IV) regression

Table 1 Summary statistics for study variables

Variable	Description	Mean	SD
Household-level characteristics			
Age	Age of household head (years)	49.53	12.34
Gender	Gender of household head (1 = male; 0 = female)	0.84	0.36
Education	Years of schooling of household head	6.55	5.19
Household size	Number of household members	6.82	3.33
Asset index	Household asset index from principal component analysis[a]	-0.01	1.64
Livestock holding	Household livestock holding in Tropical Livestock Unit (TLU)	1.20	2.46
Risk preference	Household risk preference (0 = avoid risk,…,10 = like taking risks)	5.93	3.11
Farmer group	Household member belongs to a farmer group (1/0)	0.40	0.49
Distance to CIC	Distance from home to the nearest information centre (km)	0.80	1.75
Road distance	Distance from home to the nearest all-weather road (km)	0.93	2.00
Distance to market	Distance from home to the nearest market (km)	5.75	7.55
Distance to extension	Distance from home to the nearest extension office (km)	10.85	9.48
Field-level characteristics			
Maize area	Size of maize field (hectares)	1.50	1.43
Land tenure	Household has secure rights over the cultivated field (1/0)	0.44	0.50
Field distance	Distance of field from homestead (km)	3.85	4.07
Field fertility	Soil quality is perceived to be good (1/0)	0.40	0.49
Seed rate	Quantity of seed applied (kg/ha)	26.87	25.84
Fertilizer rate	Quantity of fertilizer applied (kg/ha)	57.04	117.02
Pesticide	Expenses on pesticides (GH¢/ha)	235.68	250.37
Hired labour	Use of hired labour (1/0)	0.73	0.44
Drought shock	Field suffered from drought (1/0)	0.52	0.50
FAW shock	Field was attacked by FAW (1/0)	0.81	0.39
Observations	Number of household (field) observations	888 (1035)	

[a]The asset index was computed following the method suggested byFilmer and Pritchett (2001)

method. This method relies on finding valid instruments, which is challenging. Nonetheless, as a robustness check, we also present ATT estimates from endogenous switching models, which are an IV approach (Lokshin & Sajaia, 2004; Miranda & Rabe-Hesketh, 2006).

3.3 Outcome variables

We examined the effects of the pest risk information intervention on immediate outcomes (pest knowledge, pesticide use and adoption of IPM techniques), productivity outcomes (maize yield and income), and food security outcomes (household hunger and dietary diversity). The level of pest injury would have been another important immediate outcome variable to consider. Unfortunately, we were not able to estimate the effect of the intervention on the level of pest injury due to data limitations. To measure this variable, field scouting during the maize cropping season is necessary. However, we used data from household surveys conducted at the end of the cropping season.

Five multiple-choice test questions on FAW (see Supplementary Information) were used to assess the farmers' pest knowledge. The first question relates to how to identify FAW. Here, the farmers were shown photosheets of three caterpillar pests (African armyworm, FAW and maize stalk borer) and were asked to indicate which of them represents FAW. These three pests share some common features and can be mistaken for each other. The rest of the test questions were related to sustainable practices for FAW prevention and control, including questions on maize planting practices that can prevent or reduce FAW infestation, when and how to scout for FAW, when to control FAW, and the recommended pesticides for FAW control. For each question, the surveyed farmers had to indicate the correct answer from four possible answers that were read to them. A FAW knowledge score variable (ranging from 0 to 100%) was then constructed from the correct answers to the five knowledge test questions.

Given that a key aspect of the intervention was the dissemination of early warning pest alerts so that farmers can act against pests at the optimal time, one of our outcome indicators is a binary variable of whether or not a household took FAW control actions within the optimal timeframe. In the cropping season under study, the suggested timeframe was between 18 and 22 days after planting, as predicted by a FAW modelling and forecasting system (Lowry et al., 2022).

During the campaign, farmers were advised to use a combination of multiple pest management practices, in line with IPM principles. Hence, we used the number of IPM practices adopted by a maize farmer as one of our immediate outcome variables. The recommended IPM practices included: regular monitoring of maize fields for early detection of pest outbreaks; cultural control methods, such as timely planting of maize; intercropping and rotation of maize with non-host crops, frequent weeding (which remove alternative host plants), and fertilization to promote healthy plant growth; mechanical control, including destroying of severely infested plants, and handpicking of egg masses and larvae; and the use of recommended pesticides, most of which are biopesticides (see Table A1 in the Supplementary Information). Inspired by Rejesus et al. (2009) and Waddington et al. (2014), pesticide use was measured by three indicators: (1) whether or not the household used pesticide during the 2021 main maize cropping season; (2) the amount of pesticide used per unit of land area (litres/hectare); and (3) the number of pesticide applications during the cropping season.

Maize yield was measured as the total quantity of maize harvested in kilogram per hectare of maize area, based on farmers' self-reported information. Net maize income was computed by deducting the variable costs incurred in maize production (such as seed, fertiliser, pesticide, mechanization, labour and marketing expenses) from gross maize income. To capture broader welfare impacts and potential indirect effects of the information intervention on other crops beyond maize, we also examined the effects of the intervention on two household food security indicators.

We recognise that maize farmers' exposure to the pest risk information and subsequent adoption of IPM practices may not only affect maize yield or net maize income. For instance, given that some of the recommended IPM practices for FAW control are general good agricultural practices, it is possible that the IPM knowledge gained from the information campaign may be applied to other crops cultivated by the maize farmers, such as beans, cassava, groundnut and yam. Moreover, the adoption of IPM practices may result in household resource reallocation. For example, when implementing recommended practices such as handpicking and safe pesticide use, farmers may divert labour and financial resources away from alternative income-earning activities. Such indirect and resource reallocation effects of the campaign may not reflect in our outcome indicators related to maize productivity. Using a broader welfare measure, such as household food security, will allow us to capture some of these possible resource reallocation and indirect effects.

Our first food security indicator was constructed from items from the household hunger scale (HHS). The HHS is a perception-based measure of food security which has been validated for cross-cultural use (Ballard et al., 2011), based on three questions: whether or not in the past 30 days: 1) there was no food of any kind at home; 2) a household member went to sleep hungry; and 3) a household member went a whole day without eating. Based on household responses to these questions, we constructed a hunger variable that is equal to one if a household responded "yes" to any of these three HHS questions and zero otherwise. The second food security indicator is the household dietary diversity score (HDDS), which is constructed by a count of the number of food groups (out of 12 food groups) consumed by household members in the home during the past 24 h prior to the survey (Swindale & 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. This indicator is a proxy measure of household food access (Swindale & Bilinsky, 2006). The hunger and HDDS outcome variables allowed us to measure broader indirect effects of the pest risk information intervention.

4 Results

4.1 Descriptive results

Table 1 presents the descriptive statistics of the household- and field-level data. A majority of the households are headed by males, who on average are 50 years old and have very limited level of formal education. Our sample consists of smallholder farmers who cultivate 1.5 hectares of maize on average. Less than half of the households have secure land rights over their maize fields, and only 44% of the fields are perceived to be fertile. Table 1 also shows that about 80% of the sample fields recorded FAW infestation, and roughly half of the fields suffered from drought stress during the cropping season under study. A disaggregation of the descriptive statistics according to whether or not a sample household received the pest alert information is given in Table A2 in the Supplementary Information.

Table 2 reports the summary statistics for the outcome variables, including a disaggregation by the recipients and non-recipients of pest risk information. We find that the information recipients significantly outscored the non-recipients on all of our five knowledge tests (Fig. 2). For example, 71% of the pest risk information recipients were able to correctly identify FAW as compared to 58% of the non-recipients. In other words, the recipients outperformed their non-recipient counterparts on the knowledge test regarding the correct identification of FAW by 13 percentage points. Additionally, the information recipients scored 7 percentage points higher on a test on how to scout for FAW. Strikingly, only

Table 2 Summary statistics for outcome variables

Variable	Full sample	Recipients	Non-recipients
FAW knowledge and management			
FAW knowledge score (%)	65.82	70.95***	62.13
FAW control at the optimal time (1/0)	0.24	0.28***	0.21
Adoption of IPM practices (#)	5.13	5.39***	4.95
Use of pesticides (1/0)	0.56	0.59	0.54
Amount of pesticide used (litres/ha)	1.43	1.46	1.41
No. of pesticide sprays (#)	1.62	1.53**	1.70
Maize productivity			
Maize yield (kg/ha)	1398.19	1466.21*	1349.64
	(1082.14)	(985.69)	(1144.36)
Maize income (GH¢/ha)[a]	2930.74	3228.66***	2718.08
	(3031.95)	(3178.11)	(2907.20)
Food security			
Hunger (1/0)	0.14	0.10***	0.17
	(0.35)	(0.30)	(0.38)
Dietary diversity score (0–12)	8.07	8.20	7.97
	(2.27)	(2.42)	(2.16)

Numbers in parentheses are standard deviations

* and *** indicate statistically significant mean difference between information recipients and non-recipients at the 1% and 10% level, respectively, based on t-tests

[a]During the survey period, 1 USD = 6.24 GH¢

19% of the farmers in our sample responded correctly to the question about a recommended pesticide for FAW control. Overall, the pest risk information recipients outscored their non-recipient counterparts on FAW knowledge by roughly 9 percentage points.

Table 2 also shows that about a quarter of the sample households applied FAW control measures at the optimal time, with a significant difference between recipients and non-recipients of the pest risk information. On average, the households implemented about five different IPM practices. Figure 3 illustrates the share of recipients and non-recipients of pest risk information who adopted the various IPM practices. We find that compared to information non-recipients, a significantly higher percentage of information recipients adopted preventive cultural practices, such as timely planting, regular scouting of maize fields for signs of FAW infestation, planting of healthy certified seeds and timely weeding of maize to remove alternate host plants. Additionally, a significant proportion of information recipients than non-recipients applied recommended pesticides for FAW control,

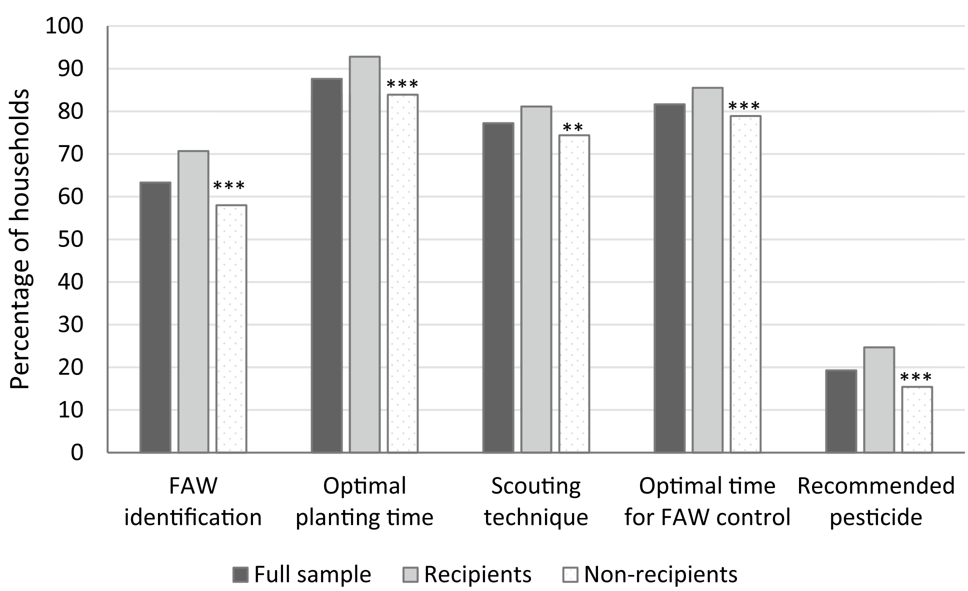
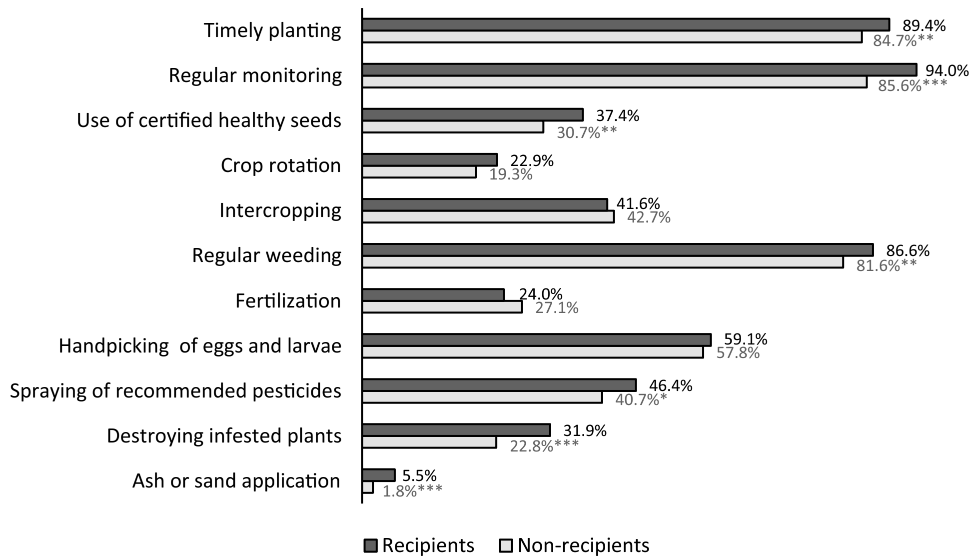


Fig. 2 Proportion of correct responses to FAW knowledge tests. *** indicates statistically significant mean difference between information recipients and non-recipients at the 1% significance level

Fig. 3 Percentage of maize fields under IPM practices (n = 1305). ***, ** and * denote that mean values for information recipients are significantly different from those of non-recipients at the 1%, 5% and 10% level, respectively



as well mechanical control methods, such as the removal and destruction of infested plants, and the pouring of ash or sand into maize whorls.

The average maize yield is nearly 1.4 tonnes/ha. Fields of information recipients have around 117 kg/ha higher maize yields and 511 GH¢/ha net returns from maize production than those of non-recipients. The results in the lower part of Table 2 indicate that significantly more non-recipients than recipients of the pest information experienced hunger. The mean dietary diversity score indicates that the sample households consumed two-thirds of the 12 food groups within the past 24 h prior to the survey.

Overall, while the results in Table 2 may be suggestive that the pest risk information intervention is associated with increased knowledge and adoption of recommended IPM practices, higher maize productivity and reduced hunger, it is important to note that these are unconditional summary statistics. The association between the information intervention and the outcome variables is properly analysed in the next section where we use doubly robust regression models to control for potential confounding factors.

4.2 Impact on agricultural outcomes

The doubly robust estimates of the relationship between the pest risk information campaign and our outcome variables are presented in Table 3. An overidentification test for covariate balancing shows an insignificant chi-squared value ($chi^2 = 13.1018$; $\rho = 0.4400$), suggesting that all the covariates are balanced by propensity score weighting, and thus it is unlikely that the treatment model is misspecified (Imai & Ratkovic, 2014).

The ATT estimates in Table 3 indicate that the pest risk information intervention is positively and significantly associated with improved farmer knowledge. In particular, the farmers who received the pest risk information outperformed their non-recipient counterparts by 9 percentage points (or 15%) on FAW-related knowledge tests, such as how to identify and scout FAW, and the appropriate measures to prevent and control the pest.

The results in Table 3 also show that the receipt of pest risk information is significantly associated with a 6-percentage point (or 30%) increase in the likelihood of a household controlling FAW at the optimal time. This is an important finding because the provision of early warning information

Table 3 Average treatment effects of pest risk information

Outcome	ATT	Robust S.E.	ATT in %
FAW knowledge score (%)	9.18***	1.40	14.94
FAW control at the optimal time (1/0)	0.06**	0.03	30.18
Adoption of IPM practices (#)	0.45***	0.12	9.11
Use of pesticides (1/0)	0.04	0.03	7.41
Amount of pesticides used (litres/ha)	0.05	0.12	3.55
No. of pesticide sprays (#)	-0.15	0.09	-8.93
Maize yield [arcsinh(kg/ha)][a]	0.28***	0.08	3.78
Maize income [arcsinh(Gh¢/ha)][a]	0.37***	0.08	4.61
Hunger (1/0)	-0.06***	0.02	-37.50
Dietary diversity score (0–12)	0.23	0.16	2.89

*, ** and *** represent 1%, 5% and 10% significance levels, respectively. All the ATT estimates are statistically significant (at least at the 10% level) even after correcting for multiple hypothesis testing using the false discovery rate approach (Benjamini & Hochberg, 1995)

[a]The maize yield and income values were inverse hyperbolic sine (arcsinh) transformed to reduce the effect of outliers. Unlike log transformation, it has the benefit of retaining zero- and negative-valued observations (Bellemare & Wichman, 2020)

on the best time to act against certain crop pests is the main difference between the studied intervention and other pest information interventions. The results also demonstrate that the information intervention is significantly correlated with an increase in the number of IPM practices adopted by recipient households by 9%. On the other hand, the information intervention has no statistically significant effect on any of the three pesticide use measures.

Table 3 also shows that households that received the pest risk information obtained an average increase in maize yield of around 4%, which represents a 54 kg/ha gain over the average maize yield for non-recipients. Additionally, they observed about a 5% increase in per hectare net income from maize production due to their exposure to the information, and the effects are statistically significant ($\rho < 0.01$).

4.3 Impact on food security outcomes

Having shown that the pest risk information intervention is associated with increased farmer knowledge, IPM adoption and productivity, we now examine whether the intervention also contributes to improved household food security. The ATT results in Table 3 show that exposure to the pest risk information is significantly associated with a reduction in the likelihood of a recipient household experiencing hunger by 6 percentage points or 37.5%. This means that the information campaign may have contributed to a decrease in the probability that the information recipients will have no food of any kind in the household, or their household member will go to bed hungry or go a whole day without eating because of household food insufficiency in the 30 days prior to the survey. Regarding our second food security indicator (dietary diversity), the ATT estimate in Table 3 indicates that the pest information campaign has no significant relationship with household dietary diversity score.

4.4 Robustness checks

As mentioned, we test the robustness of the doubly robust estimates by applying endogenous switching models. A robust identification of the models requires the inclusion of at least one variable that affects the receipt of the pest risk information but does not have a direct influence on our outcome variables (i.e., exclusion restriction variable). We use the distance from a household's residence to the nearest CIC as our exclusion restriction variable. It is expected that households living in close proximity to CIC, which is the main channel used in the information campaign, are more likely to be recipients of the pest risk information due to better access and exposure to the campaign information, as well as reduced travel (and thus saving on time and costs) if there is a need to visit the CIC to seek a better understanding of a broadcasted message. On the other hand, we do not envisage the distance to the nearest CIC variable to directly affect our outcomes of interest, particularly after controlling for variables reflecting household access to other related sources of information and institutional support, such as extension services and market.

Table 4 Endogenous switching estimates of the effects of pest risk information

Outcome	ATT	Robust S.E.	ATT in %
FAW knowledge score (%)	14.08***	0.46	24.79
FAW control at the optimal time (1/0)	0.06***	0.01	28.57
Adoption of IPM practices (#)	1.47***	0.04	37.50
Maize yield [arcsinh(kg/ha)]	0.64***	0.02	9.08
Maize income [arcsinh(Gh¢/ha)]	0.71***	0.02	9.32
Hunger (1/0)	-0.14***	0.01	-58.33
Dietary diversity score (0–12)	-1.75***	0.04	-17.62

*, ** and *** represent 1%, 5% and 10% significance levels, respectively. All the ATT estimates are statistically significant (at least at the 10% level) even after correcting for multiple hypothesis testing using the false discovery rate approach (Benjamini & Hochberg, 1995). Endogenous switching estimates for the three outcomes related to pesticide use were not possible due to model convergence problems

Results from a falsification test proposed by Di Falco et al. (2011) suggest that the selected instrument is relevant. Specifically, we find that the distance to the nearest CIC variable is a significant determinant of the receipt of pest risk information, but it is not significantly correlated with any of the outcomes of the information non-recipients (see Table A3 in the Supplementary Information). This notwithstanding, we cannot completely rule out the possibility that distance to CIC can affect our outcome variables through other pathways besides the information intervention. Hence, the endogenous switching model results should also be treated as associations rather than causal effects. It should be mentioned that although the information was transmitted through CIC and SMS, the distance to CIC variable is a relevant instrument because only 13 households in the treatment group did not receive the information through CIC. We obtained similar results even when we excluded these 13 households from the endogenous switching analysis.

Similar to the doubly robust results, we find that the pest risk information intervention is significantly associated with improved farmer knowledge of FAW, higher adoption of recommended IPM practices, increased maize productivity and a reduction in hunger (Table 4). However, the magnitude of the ATT estimates is noticeably greater when using the endogenous switching models. For instance, the ATT estimates for the productivity outcome variables with the endogenous switching models are about twice that obtained using the doubly robust estimator. The ATT estimates in Table 4 also indicate that the pest information campaign has a significant negative relationship with household dietary diversity score. We conclude that while the significant association between the information intervention and the outcome variables are generally consistent across the two estimation models, the magnitudes of the ATT estimates are sensitive to the model employed. Given that the validity of the instrument could be challenged, we report the doubly robust estimates as our primary results, which, at worst, underestimate the true effect of the intervention.

4.5 Spillover checks

Our ATT estimates depend on the stable unit treatment-value assumption, which rules out the possibility of externality or spillover effects. However, one could argue about the possibility of information and knowledge diffusion between information recipients and non-recipients, leading to a violation of this assumption and an under-estimation of the treatment effects. In this section, we explore potential spillovers from recipients to non-recipients of the pest risk information. We do this by simply comparing the outcomes of non-recipients in intervention communities (n = 183) with that of the non-recipients in control communities (n = 328). The underlying logic is that if there is a strong spillover effect, the non-recipients in the intervention communities will significantly outperform their counterparts in the control communities, particularly in terms of outcomes directly related to the information intervention (i.e., knowledge and IPM adoption outcomes). A similar approach has been used in previous research (e.g., Rola et al., 2002; Tripp et al., 2005; Tambo & Wünscher, 2018; Bryan & Mekonnen, 2023) to examine spillover and knowledge diffusion effects of agricultural extension and development interventions.

The doubly robust estimation results in Table 5 show that whether or not the non-recipient household is located in an intervention community is not significantly related to any of the three immediate outcome variables, suggesting that there is no strong spillover effects of the information intervention.

Table 5 Testing for spillover effects

Outcome	ATT	Robust S.E.	ATT in %
FAW knowledge score (%)	3.03	2.37	5.24
FAW control at the optimal time (1/0)	0.01	0.04	4.41
Adoption of IPM practices (#)	0.11	0.17	2.27
Use of pesticides (1/0)	0.05	0.05	9.60
Amount of pesticides used (litres/ha)	-0.19	0.19	-12.75
No. of pesticide sprays (#)	0.10	0.13	6.67
Maize yield [arcsinh(kg/ha)]	0.24	0.23	3.39
Maize income [arcsinh(Gh¢/ha)]	-0.17	0.15	2.10
Hunger (1/0)	0.08	0.08	32.00
Dietary diversity score (0–12)	0.03	0.20	0.39

The ATT estimates are not statistically significant, even at the 10% level

4.6 Gender-differentiated effects

Finally, we investigate whether the observed positive outcomes of the pest risk information campaign differ by the gender of information recipient. To this end, we disaggregate the households into male recipient households (n = 121), female recipient households (n = 79) and joint recipient households (n = 170), based on data on household members who mainly received or listened to the pest risk information.[1] Join recipient means that both spouses in a household were recipients of the disseminated information. The doubly robust estimates of the ATTs for the three gender groups are presented in Table 6.

We find evidence of significant increases in knowledge of FAW among all households, irrespective of the gender of the information recipient. However, the pest risk information is significantly associated with greater adoption of IPM practices and maize productivity for only the female and joint recipient households. The results also show that the information campaign has a stronger significant negative effect on hunger situation and a positive effect on dietary diversity among the joint recipient households.

5 Discussion

This study corroborates previous evidence on the pivotal role of mass media campaigns in enhancing farmers' pest knowledge (Escalada et al., 1999; Flor & Singleton, 2011; Huân et al., 1999), particularly during the outbreak of a new invasive pest, such as FAW (Rware et al., 2021; Tambo et al., 2019). The study results demonstrate that the FAW risk information campaign has contributed to the timely adoption of IPM practices against FAW in Ghana. Similar significant effects of mass media information campaigns on the uptake of IPM practices have been reported in several previous studies (e.g., Larochelle et al., 2019; Tambo et al., 2019). Our findings also resonate with arguments that information constraint is a major barrier to IPM adoption and diffusion in developing countries (Alwang et al., 2019; Parsa et al., 2014). With the proliferation of ICTs in developing countries, studies on the effectiveness of mass media methods in promoting agricultural technology adoption among smallholder farmers are increasingly based on ICT channels such

[1] This analysis excludes seven observations for which the main information recipient was a child in the household. The data did not capture the gender of the child.

Table 6 Differential effects by gender of information recipient

	ATT	Robust S.E.	ATT in %
FAW knowledge score (%)			
Male	8.10***	1.99	12.86
Female	12.95***	2.76	21.61
Joint	8.29***	1.87	13.24
FAW control at the optimal time (1/0)			
Male	-0.01	0.04	-4.76
Female	0.06	0.06	27.27
Joint	0.10**	0.04	45.45
Adoption of IPM practices (#)			
Male	-0.15	0.18	-3.18
Female	1.05***	0.25	21.26
Joint	0.73***	0.15	14.51
Use of pesticides (1/0)			
Male	0.02	0.04	3.64
Female	0.04	0.06	7.55
Joint	0.08**	0.04	14.81
Amount of pesticides used (litres/ha)			
Male	-0.22	0.19	-16.79
Female	0.07	0.23	5.22
Joint	0.21	0.18	14.38
No. of pesticide sprays (#)			
Male	-0.17	0.14	-12.23
Female	-0.23	0.22	-12.78
Joint	0.16	0.10	9.88
Maize yield [arcsinh(kg/ha)]			
Male	0.15	0.12	1.98
Female	0.29*	0.16	3.96
Joint	0.40***	0.11	5.47
Maize income [arcsinh(Gh¢/ha)]			
Male	0.32	0.22	3.89
Female	0.37**	0.18	4.69
Joint	0.42***	0.11	5.29
Hunger (1/0)			
Male	-0.03	0.03	-23.08
Female	-0.05*	0.03	-33.33
Joint	-0.11**	0.05	-57.89
Dietary diversity score (0–12)			
Male	-0.32	0.21	-4.31
Female	-0.32	0.25	3.76
Joint	1.05***	0.19	13.27

*, *** and *** represent 1%, 5% and 10% significance levels, respectively

as mobile phone (Fu & Akter, 2016; Larochelle et al., 2019; Mwambi et al., 2023); radio (Ragasa et al., 2021; Rware et al., 2021); video or television (Abate et al., 2023; Areal et al., 2020); or a combination of these channels (Dzanku et al., 2022; Flor & Singleton, 2011; Tambo et al., 2019). Our findings suggest that CICs can also be a useful mass communication channel for agricultural information dissemination in developing countries.

While the information campaign is significantly associated with IPM uptake, it did not lead to a significant reduction in pesticide use. This is not surprising because the IPM recommendations for FAW control included the use of pesticides as a last resort. The severe damages caused by the FAW invasion has stimulated widespread use of synthetic pesticides among smallholder farmers in several African countries, including Ghana (Tambo et al., 2020). Unfortunately, indiscriminate use of synthetic pesticides poses human health and environmental risks. Hence, the mass media campaign emphasised on the use of lower-risk pesticides, particularly biopesticides, which are considered safer and environmentally friendly alternatives to synthetic pesticides (Bateman et al., 2018). Our results show that a significant share of information recipients than non-recipients used recommended pesticides for FAW control, which is encouraging. Given that the data used in this study allowed us to examine only the short-term effects of the information intervention, it is possible that there would be a significant reduction in pesticide use when IPM practices that help to avoid or reduce FAW damage are adopted. Thus, it would be interesting for further studies to investigate if the farmers have reduced their pesticide use in subsequent cropping seasons. Our results are in contrast to a recent study by Tambo et al. (2023b) who found that mass media campaigns significantly contributed to an increase in the use of pesticides for controlling FAW in East Africa, but are consistent with a previous research showing that a mass media campaign targeting rice producers in south Vietnam did not have a statistically significant pesticide reduction effect (Rejesus et al., 2009).

We found that the knowledge gained from the pest risk information intervention and the subsequent adoption of early warning and IPM measures translated into average maize yield and net maize income gains of about 4%. While the yield gain seems modest, it is in line with findings from a meta-analysis by Fabregas et al. (2019) showing that providing agricultural information through digital technologies (which are also mass media channels) increased yields by 4% in sub-Saharan Africa.

Households exposed to the mass media campaign had a significantly lower likelihood of experiencing hunger, as measured by the household hunger scale. This is possibly because the modest increase in maize yield can help cushion short-term household food shortages, especially given that maize is a major staple food in Ghana, with about three-quarters of maize consumption in the country coming from own production (MoFA-IFPRI, 2020). Moreover, the information recipients could spend the marginal income gains on food for household consumption. While the pest risk information campaign may have contributed to improved household food availability and hunger alleviation, at least in the short run, it did not lead to a more diverse food consumption, which is important for nutrition. However, it should be noted that our dietary diversity indicator (HDDS) does not consider the frequency of consumption of the different food groups. Moreover, although the HDDS is strongly linked with improved nutritional outcomes (Headey & Ecker, 2013), it better reflects household food access and socio-economic status (Kennedy et al., 2011; Swindale & Bilinsky, 2006). Hence, further research involving measures that can better proxy for nutrient adequacy [such as individual dietary diversity scores, consumption of micronutrient-rich foods or anthropometric indicators (Headey & Ecker, 2013; Manikas et al., 2023)] would be useful to assess the nutritional outcomes of the pest risk information intervention.

Overall, the study results suggest that apart from the previously documented positive effects of mass media campaigns on awareness and adoption of improved agricultural technologies and practices (e.g., Fu & Akter, 2016; Tambo et al., 2019; Larochelle et al., 2019; Ragasa et al., 2021) and increased crop yields (Dzanku et al., 2022; Fabregas et al., 2019; Van Campenhout et al., 2021), they are also significantly associated with some income and welfare gains.

The gender-disaggregated results show that female recipient households benefited more from the pest risk information intervention than male recipient households, and the positive effects are more pronounced for joint recipient households. This is noteworthy, given the well-known gender gap in access to agricultural production resources, including information and extension services (Quisumbing & Doss, 2021). The greater benefits for joint recipient households are possibly due to a reinforcement of the information learned when both spouses are recipients, and intra-household bargaining. These results also add to previous findings on the importance of facilitating joint male and female participation in agricultural extension activities. For example, in a study in Democratic Republic of Congo, Lambrecht et al. (2016) found that the rate of adoption of integrated soil fertility management practices is highest among joint male and female participants of an agricultural extension programme. Likewise, Ragasa et al. (2019) observed that joint male and female access to agricultural extension and advisory services has a stronger effect on household food security in Malawi.

We also found evidence of no significant diffusion of FAW and IPM-related knowledge to other farm households who reside in the same communities as the information recipients (i.e., spillover effect). This is plausibly because the short time period between the information intervention and this study may not have allowed the diffusion of knowledge between recipients and non-recipients of the information. Moreover, as also found in previous studies, IPM is a complex, knowledge-intensiveness technology, and information about it is not easily disseminated through informal farmer-to-farmer communications (Feder et al., 2004; Rola et al., 2002; Tripp et al., 2005). It should be pointed out that our method of assessing potential spillover effects is a crude one; hence, we can only cautiously conclude that we do not find evidence of a strong spillover effects of the pest risk information intervention. Future research that explicitly accounts for spillover effects (e.g., through experimental designs) would be useful to confirm our findings.

6 Conclusion

In this study, we evaluated the impact of a unique agricultural information intervention that provides early warning pest alerts and IPM-based advice through mass media channels to African smallholders. In particular, we analysed the short-term effects of pest risk information on several outcomes ranging from pest knowledge to household well-being. We used survey data from 888 maze producers and 1305 maize fields in Ghana, and applied doubly robust and switching regression models to reduce sample heterogeneity and selection bias. Our findings contribute to the literature on sustainable pest management in smallholder farming systems and the effectiveness of mass media campaigns in improving agricultural productivity and farmers' livelihoods.

Treatment effect estimates showed that exposure to the pest risk information campaign is significantly associated with increases in farmers' knowledge on how to identify, monitor and control FAW, as measured by knowledge test scores. We also found evidence that the receipt of the pest risk information resulted in a 30% increase in the likelihood of FAW pest control at the optimal time among the information recipients. This is an important finding because applying pest control measures at the wrong time may not be effective, and will instead raise production costs (labour and pesticide costs), thereby reducing farmers' incomes. Hence, a key aspect of the intervention under study was the use of a combination of satellite observations, weather data and pest modelling to produce pest risk forecasts and then alert farmers on when and how to take actions against pests.

Our analysis also showed that the pest risk information induced IPM adoption. Specifically, the information recipients had a 9% higher likelihood of adopting multiple IPM practices, which include cultural and physical control methods as well as judicious use of pesticides. We also found suggestive evidence that with the knowledge gained from the information campaign and the subsequent adoption of IPM practices, the farmers achieved around 4% increase in maize yield and income. Going beyond the farm-level outcomes, results showed that the receipt of the pest risk information is significantly associated with a lower probability of suffering from hunger. However, the information campaign is not linked with better household dietary diversity. A gender disaggregated analysis showed that female recipient households had greater benefits from the information intervention than their male counterparts, but the effects were generally larger for households where the information was jointly received by both spouses.

Overall, our findings imply that the dissemination of early warning pest alerts in combination with actionable IPM information can play an essential role in boosting the adoption of sustainable crop protection technologies, and ultimately improve the standard of living of farm households in the face of increasing threats from invasive pests. This can in turn contribute to the achievement of the global goal of ending hunger by 2030. Another important implication from our results is that the effectiveness of pest risk information can be maximized by facilitating joint male and female access to the disseminated information. In our study context, CICs can provide a starting point, as they reach all types of farmers (including rural women) with information. If well regulated, CICs hold promise as a low-cost mass media channel for agricultural information dissemination in rural settings. For future research, it would be interesting to assess the relative effectiveness of alternative mass media channels for disseminating pest risk information to smallholder farmers. This was not possible in the current study because a large share of the farmers received the campaign information via CICs only.

It should be emphasised that this study only measured the short-term effects of the pest risk information intervention. It is possible that the productivity and welfare gains could rise in the future when farmers have had much experience in applying the knowledge gained, particularly given the complexity of IPM practices. Hence, future research involving panel data analysis (which can also better account for unobserved heterogeneity) will be necessary to investigate the long-term effects of the information campaign. Finally, the finding that the gains from the pest risk information do not translate into greater household dietary diversity merits further investigation. While the objectives of the studied intervention are not nutrition-related, any positive indirect effect on dietary quality or nutrition outcomes will be pertinent, particularly in light of the alarming levels of malnutrition among rural populations (FAO et al., 2021). For instance, the intervention can be used to promote nutrition-sensitive agriculture by integrating some nutrition education into pest-related campaign messages.

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Data availability The data used in this study are available from the corresponding author upon reasonable request.

Declarations

Competing interests Justice A. Tambo, Fredrick Mbugua, Solomon Agyemang Duah, Birgitta Oppong-Mensah and Frances Williams are employed at CABI, the institution that manages the pest risk information service (PRISE) project.

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