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Using mass media campaigns to change pesticide use behaviour among smallholder farmers in East Africa

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ABSTRACT

Pesticides are an important and widely used tool for crop protection, but they also pose significant risks to agricultural sustainability, human health and the environment. In this paper, we examine whether mass media campaigns can help improve pesticide knowledge and change pesticide use behaviour among smallholder farmers in Rwanda and Uganda. We also assess the individual and combined effects of the campaign channels, which include interactive radio, plant health rallies, mobile SMS and video screenings. Applying a doubly robust method to survey data from 1327 maize-producing households across the two countries, we find that the mass media campaigns are significantly associated with improved farmer knowledge of pesticide risks and safety precautions. While the campaigns appear not to have discouraged the use of synthetic pesticides, they are significantly associated with increased adoption of safer alternatives to pesticides, including sustainable integrated pest management practices. The campaigns are also significantly correlated with increased use of protective equipment against pesticide exposure in both countries and reduced incidence of pesticide-related illnesses in Rwanda. We conclude that mass media campaigns (particularly using multiple complementary channels) can be effective in enhancing farmers' knowledge about pesticide risks and safety measures, and promote the adoption of safer pest management strategies.

1. Introduction

Pesticides are an important and popular tool for crop protection worldwide. High levels of pest pressure, along with increasing accessibility and affordability of pesticide products, and weak regulatory enforcement, have fuelled a surge in pesticide use in sub-Saharan Africa in recent decades (de Bon et al., 2014; Williamson et al. 2018; Andersson and Isgren 2021; Haggblade et al., 2022). For instance, the tonnage and value of pesticides imported annually into East Africa have nearly tripled in the past decade (FAOSTAT 2022).[1] One of the major pests that have spurred increased pesticide use among smallholder farmers in the past five years is fall armyworm (FAW), *Spodoptera frugiperda* (Bateman et al., 2018; Yang et al., 2021; Haggblade et al., 2022). Recent evidence has shown that more than two-thirds of a sample of farmers in Rwanda and Uganda (our study countries) used synthetic pesticides for FAW control in maize production (Tambo et al., 2020).

The increased use of pesticides poses significant risks to agricultural sustainability and human and environmental health, some of which include increased resistance of pests to pesticides, land pollution, food and water contamination, short- and long-term health problems, poisoning of pollinators and beneficial insects, and loss of biodiversity (Wilson and Tisdell 2001; Kim et al., 2017; Sheahan et al., 2017; Ataei et al., 2021). These risks are exacerbated by the fact that pesticide malpractices are common among smallholder farmers, including the use of highly toxic and restricted products, the use of inappropriate dosage, insufficient use of personal protective clothing (PPE), lack of adherence to re-entry and pre-harvest intervals, and indiscriminate disposal of pesticide wastes (Okonya and Kroschel 2015; Andersson and Isgren 2021; Tambo et al., 2021). The literature studying pesticide use and practices has often pointed out that smallholder farmers lack access to

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[1] Globally, agricultural pesticide use has about doubled in the past three decades. It is estimated that in 2020, about 70,000, 106,000, 470,000, 660,000 and 1.4 million tonnes of pesticides were used for agricultural purposes in Europe, Africa, Oceania, Asia and the Americas, respectively (FAOSTAT 2021).

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information and training on pesticides and their attendant risks (Ntow et al. 2006, de Bon et al., 2014; Andersson and Isgren 2021).

Growing concerns over the negative effects of synthetic pesticides on human health and the environment have drawn attention to the need to promote alternatives to a sole reliance on pesticides, such as integrated pest management (IPM) (de Bon et al., 2014; Matthews 2020; Deguine et al., 2021). IPM involves the management of pests by combining different environmentally friendly methods, including resistant crop varieties, cultural and mechanical practices, biological control and rational use of pesticides, as a last resort. Evidence shows that IPM programmes are providing economic, health and environmental benefits (Muriithi et al., 2016; Midingoyi et al., 2019; Norton et al., 2019). Nonetheless, IPM uptake is very low in many developing countries, with lack of information and insufficient training identified as among the major reasons for the low rate of adoption (Parsa et al., 2014; Alwang et al., 2019; Deguine et al., 2021).

In efforts to address these challenges, there has been an increasing number of studies aimed at understanding the role of agricultural information and extension services in changing pesticide safety behaviour and in encouraging IPM adoption among smallholder farmers (e.g., Hruska and Corriols 2002; Gautam et al., 2017; Schreinemachers et al., 2016; Clausen et al., 2017; Goeb et al., 2020; Goeb and Lupi 2021; Tambo et al., 2021). These previous studies were largely based on in-person or face-to-face information delivery methods, such as farmer training, farmer field schools, plant clinics and extension agent visits. For instance, Gautam et al. (2017) showed that the training of vegetable farmers in IPM led to a significant increase in the adoption of IPM practices and safer use of pesticides in Bangladesh. Goeb et al. (2020) and Goeb and Lupi (2021) found that a farmer-to-farmer pesticide training programme in Zambia was effective in increasing pesticide knowledge and in stimulating the demand for less toxic pesticides, but not the demand for PPE against pesticide exposure. Tambo et al. (2021) also reported that the plant clinic extension approach is associated with a significant increase in pesticide use and the adoption of environmentally-friendly pest management practices. A major criticism of these in-person extension approaches is their limited scale and high costs (Anderson and Feder 2007; Aker 2011).

In this paper, we investigate whether mass media campaigns can help improve pesticide knowledge and safety practices among smallholder farmers. Our study is based on information campaigns that were implemented in Rwanda and Uganda to provide farmers with structured and reliable information on how to sustainably manage FAW using IPM and safe pesticide use practices. The information channels used in disseminating the campaign messages include interactive radio programming, mobile short message service (SMS), video screenings and plant health rallies (PHRs). The individual and combined effects of these information channels are also assessed in this study.

Unlike the previous-related studies mentioned above, we focus on interventions that leveraged information and communication technologies (ICTs), which allow knowledge transfer to a wider population in a cost-effective and timely manner than in-person extension services (Aker 2011). Moreover, unlike most previous studies, we compare the effectiveness of different information delivery methods and also use data from two countries, which increase the external validity of our findings. Our study also contributes to the limited literature on the effectiveness of ICT-based information delivery channels in promoting the uptake of sustainable crop protection practices (Larochelle et al., 2019; Tambo et al., 2019; Rware et al., 2021; Tambo et al., 2022).

The rest of this paper is structured as follows. The next section describes how the mass media campaigns were implemented, the data used in the analyses and the estimation methods. The study results are presented in section 3 and discussed in section 4, while the last section concludes with a highlight of key findings, as well as the implications and limitations of the study.

2. Material and methods

2.1. The mass media campaigns in Rwanda and Uganda

In efforts to promote safe pesticide use among farm households in Rwanda and Uganda, the Centre for Agriculture and Biosciences International (CABI) in collaboration with the Rwanda Agriculture and Animal Resources Development Board (RAB) and Uganda's Ministry of Agriculture, Animal Industries and Fisheries (MAAIF) and several local partners implemented information campaigns in major maize-producing areas of the two countries as part of the CABI-led Plantwise programme. The campaigns were implemented between March and August 2018 in Buliisa and Masindi districts of Uganda and between September 2019 and December 2020 in Bugesera and Rwamagana districts of Rwanda. Before launching the campaigns, country-specific stakeholder consultation meetings were held among the implementing partners to design the campaign messages. In each country, three complementary communication channels were used to disseminate harmonised information on safe pesticide use and sustainable management of FAW. The channels used were radio, mobile SMS and PHRs in Rwanda; and radio, mobile SMS and video screenings in Uganda. The campaign messages were delivered in Kinyarwanda and Runyoro languages of Rwanda and Uganda, respectively.

The underlying theory of change of the campaigns is that while information is not sufficient in itself to influence behavioural change, it is a necessary part of the behavioural change process. Therefore, lack of information is a key obstacle to the adoption of pesticide safety practices and safer alternatives to pesticides. Campaigns are designed to take account of local context and other barriers, for example by providing actionable information on technologies and practices that are available locally, affordable and feasible for the target audience. Hence, using mass communication channels as a behavioural change tool to disseminate harmonised and actionable information to a wide range of farmers is expected to lead to improved knowledge and trigger behavioural changes in terms of safe pesticide practices and the adoption of environmentally-friendly alternatives to pesticides, such as IPM. At the same time, men and women access information in different ways. Hence, using complementary communication channels is expected to enable different members of farm households to access information directly, reinforcing the messages within the household, thereby enabling a better understanding of complex messages, which can translate into more positive outcomes, such as the adoption of complex IPM techniques.

In Rwanda, seven pre-recorded radio drama episodes that were acted by professional actors were aired three times over a 10-week period by the Rwanda Broadcasting Agency. Each episode lasted approximately 2 min. The radio campaign in Uganda consisted of a 10-week interactive series developed by Farm Radio International and broadcasted by Radio Kitara. Each series included the airing of pre-recorded information and live interviews with crop health experts over a 1-h period, with a repeat broadcast per week. In both countries, the radio broadcasts were complemented with phone-ins during which invited experts responded to farmers' queries about the campaign topics. In addition, two digital service companies (BK TecHouse Limited in Rwanda and Hamwe East Africa in Uganda) were contracted to deliver SMS campaign messages to databases of mobile phone numbers of 15000 and 45,000 maize farmers in the study regions in Rwanda and Uganda, respectively. The farmers were sent about three structured text messages (each of about 160 characters) per week during the 10-week campaign period.

In Uganda, a media organization called Peripheral Vision International was engaged to produce an 8-min video on the campaign topics and screen it in about 70 communities across the two districts using motorcycle-mounted microcinemas. Each community-based video screening session lasted about an hour and was attended by 30 farmers on average. In total, 1079 and 1180 people participated in the video screenings in Masindi and Buliisa districts, respectively. The sessions were facilitated by a content expert who answered questions posed by the attendees. Finally, as part of the information campaign in Rwanda, PHRs were organised in 9 and 10 sites in Bugesera and Rwamagana districts, and were attended by a total of 1106 and 1147 farmers, respectively. The rallies were held at community centres, markets and places where farmers often congregate. The dates and venues for the PHRs were pre-advertised through local leaders and extension workers. Each PHR took up to an hour and was facilitated by a team of three or four experts. The face-to-face nature of PHRs allowed actual demonstrations of pesticide safety measures to the participating farmers.

2.2. *Data and sample characteristics*

Our analysis is based on survey data obtained from 720 to 607 maize-producing households respectively in Rwanda and Uganda in East Africa. All the surveyed households had observed FAW damage in their maize fields. The data were collected by trained local enumerators using tablet-based questionnaires that were programmed in Open Data Kit (ODK) software. The questionnaires captured information on household demographic characteristics and asset endowments, exposure to the campaign channels, pesticide knowledge assessments, pesticide use and safety practices, adoption of crop protection practices, and access to institutional support services. The interviewed households were selected using a multi-stage sampling method, involving purposive sampling of districts and sub-counties or sectors, and random sampling of villages and farm households.

In Uganda, the data were collected between October and November 2018 in Buliisa and Masindi districts in mid-Western Uganda, where the information campaigns were implemented. Within each district, we purposively selected three sub-counties based on the geographic coverage of the radio and video campaigns, and the importance of maize production. The selected sub-counties include Biiso, Kihungya and Ngwedo in Buliisa district; and Bwijanga, Mirya and Pakanyi in Masindi district. Within each sub-county, we randomly selected between four to eight villages based on the size of the sub-county. Lastly, we randomly selected and interviewed about 10–20 maize-growing households per village depending on the size of the village. In total, our sample comprises 202 and 405 maize producers from Buliisa and Masindi districts, respectively.

The Rwanda data were collected in March 2021 from maize producers in Bugesera and Rwamagana districts in the Eastern province of the country. These two districts are major maize-growing districts where the radio, SMS and PHR campaigns were implemented. Four main maize-producing sectors were selected from each district.[2] The selected sectors include Gashora, Juru, Mayange and Nyamata in Bugesera district; and Fumbwe, Gahengeri, Gishari and Mwulire in Rwamagana district. Five villages were then chosen from each sector by purposively sampling one village where a PHR has been held, and a random sampling of four villages. This was followed by a random sampling of 15–20 households per village for inclusion in the study. In total, the sample consists of 360 households each from the two districts.

Table 1 presents descriptive statistics for the sample households in the two study countries. Most of the households are headed by middle-aged males with very limited level of formal education, particularly in Rwanda where the head has completed less than five years of schooling. Maize is cultivated on less than half a hectare of land in Rwanda and about 1 ha in Uganda, reflecting a sample of small-scale maize-producing households. The maize plot area constitutes a half and a third of the total cultivated area in Rwanda and Uganda, respectively. The relatively smaller farm size in Rwanda is not surprising, given that it is a small densely populated country and covers a land area that is almost 10 times smaller than that of Uganda. In both countries, nearly 90% of the households own mobile phones and more than two-thirds of them also have access to radio. Proportionally more households in Rwanda than in Uganda are members of farmer groups, which are an important source of social capital and agricultural information. On the other hand, access to credit and off-farm income earning activities, which can help relax household liquidity constraints, is higher in Uganda than in Rwanda. Table 1 also shows that the households in Rwanda live in closer proximity to two traditional sources of farmer advisory services (extension agencies and agro-input dealers) than their counterparts in Uganda.

Table 1
Summary statistics for household characteristics.

Variable	Rwanda		Uganda	
	Mean	SD	Mean	SD
Age of household head (years)	47.84	12.30	43.25	13.63
Gender of household head (1 = male)	0.83	0.37	0.85	0.36
Number of years of formal education of household head (#)	4.51	2.68	7.34	3.76
Number of household members (#)	5.25	2.03	6.82	3.30
Maize area cultivated by household (hectares)	0.35	0.42	1.23	2.56
Amount of land cultivated by household (hectares)	0.70	0.82	3.54	7.45
Number of livestock owned in Tropical Livestock Unit (TLU)	0.86	1.83	1.28	3.42
Household durable asset index (constructed using PCA)[a]	−0.01	1.58	−0.15	1.70
Household owns a radio (1/0)	0.69	0.46	0.85	0.36
Household owns a phone (1/0)	0.89	0.31	0.89	0.32
A household member belongs to a farmer association (1/0)	0.49	0.50	0.28	0.45
Household has access to credit (1/0)	0.37	0.48	0.52	0.50
Household engages in off-farm income activities (1/0)	0.20	0.40	0.49	0.50
Distance from household to the nearest agro-input shop (km)	2.40	2.21	3.93	5.35
Distance from household to the nearest extension office (km)	2.18	2.19	6.79	6.00
District location of household (1 = Rwamagana; 0 = Bugesera)	0.50	0.50		
District location of household (1 = Masindi; 0 = Buliisa)			0.67	0.47
Number of observations	720		607	

[a] PCA = Principal component analysis.

2.3. *Empirical strategy*

As mentioned earlier, the goal of this study is to estimate the effects of mass media campaigns on pesticide use and safety practices. This can be expressed as:

$$Y_i = \beta_0 + \beta_1 IC_i + \beta_2 X_i + \mu_i \tag{1}$$

Y_i represents the outcome variables for household *i*. We use five different outcome variables. The first relates to farmers' pesticide knowledge, which is assessed using five multiple-choice test questions. The five questions measure knowledge about: (1) the risks of pesticides to animal and human health; 2) the negative effects of pesticides on the environment; (3) the importance of using protective equipment when mixing or spraying pesticides; (4) the risks of re-using empty pesticide containers for household purposes; and (5) the need to observe pre-harvest intervals. For each question, the surveyed farmers were asked to indicate if they 'agree', 'disagree' or 'don't know'. The correct answers to the five test questions are aggregated to generate a pesticide knowledge score, expressed in percentage.

The second outcome measure is a binary variable indicating whether or not a household applied synthetic pesticides to control FAW. Given that the information campaigns emphasised on the use of several alternatives to synthetic pesticides for the management of FAW, in line with the principles of IPM, the third outcome variable is measured by the

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[2] A sector is the third administrative unit in Rwanda (i.e., province, district and sector).

number of non-chemical pest management strategies adopted in maize production by a household. Such strategies include intercropping and crop rotation with non-host plants, regular monitoring of farm to check for pest infestation, handpicking of larvae, destruction of infested plants, field sanitation, and biological control measures. The next outcome is the number of different PPE items (i.e., goggles, masks, coverall, gloves and rubber boots) used by a household while mixing or applying pesticides. The final outcome variable relates to the number of acute pesticide-related health symptoms reportedly experienced by a household member or farm worker while working with pesticides. It is expected the receipt of information on safe and prudent use of pesticides will encourage farmers to use protective gears and pesticide alternatives, which can help to reduce the incidence of pesticide-related illnesses.

The main explanatory variable of interest is IC_i, which is measured in two ways. The first is a binary treatment variable taking the value of one if a household received pesticide information through the mass media campaigns, and zero otherwise. The second measure of IC_i represents the different channels through which a household received the pesticide information. This allows us to estimate the heterogeneous effects of the campaign channels on our outcome variables. Given that three information channels were used in the campaigns in both study countries, we have multi-valued treatments with seven possible treatment levels. For example, a surveyed household in Rwanda could have received the information through any of the following channels: (1) Radio only; (2) SMS only; (3) PHR only; (4) Radio + SMS; (5) Radio + PHR; (6) SMS + PHR; or (7) PHR + RD + SMS. Thus, the differential effects of the three campaign channels can be estimated by comparing the outcomes of households in treatment groups (1) to (7) with the outcomes of the households that did not receive the pesticide information.

X_i denotes a vector of covariates, including household head characteristics, such as age, gender and level of education; household size and resource endowment; access to institutional services, such as credit, off-farm income earning activities, group membership and other information sources; and district dummies. A description of the explanatory variables is presented in Table 1. μ_i is a random error term, and the βs are the parameters to be estimated.

We recognise that there is a potential selection bias problem when estimating the effects of the mass media campaigns (equation (1)), given that exposure to the campaign channels is not based on random assignment. To reduce this potential bias, we apply the inverse-probability regression adjustment method, which is also known as the doubly robust estimation technique (Wooldridge 2010). It should be noted that while the doubly robust method can correct for selection bias due to observable characteristics, it cannot control for unobserved heterogeneity. Unfortunately, the mass media campaigns studied here are not based on experimental designs, which can properly address unobserved heterogeneity bias. Moreover, we are unable to use non-experimental estimators that rely on instrumental variables (IV) approach to correcting for selection bias problems because of the difficulty in identifying valid instruments, particularly given that multiple mass media channels were used in the information campaigns. Hence, we refer to the estimated relationships between IC_i and Y_i in equation (1) as correlations rather than causal impacts.

The doubly robust method follows three steps. First, logit regression models are used to estimate the probability of a household receiving pesticide information through the mass media campaigns (i.e. treatment model). Second, using inverse-probability weights obtained from step one, weighted outcome models are fitted to obtain the predicted outcomes for the recipients and non-recipients of the pesticide information (outcome models). Note that the outcome models are fitted using linear, probit and Poisson regression models for continuous, binary and count outcome variables, respectively. Lastly, the means of the predicted outcomes are then used to estimate the average treatment effect on the treated (ATET), which quantifies the effects of the mass media campaigns.[3]

An attractive feature of the doubly robust method over other commonly used selection-on-observable estimators, such as propensity score matching (PSM), is its doubly robust property, meaning that if either one of the treatment or outcome models is mis-specified, the ATET estimates would still be consistent (Imbens and Wooldridge 2009). Nonetheless, for comparison purposes, we also use PSM method to examine the effects of the mass media campaigns. The PSM method also allows us to use the Rosenbaum bounding approach (Rosenbaum 2002) to test the sensitivity of the ATET estimates to unobserved heterogeneity bias.

3. Results

3.1. Descriptive results

Fig. 1 shows that approximately three-quarters of the sample households in Rwanda and Uganda received safe pesticide use information through at least one of the campaign channels. Radio was the most popular source of pesticide information in both countries, especially in Uganda. This is not surprising, given that radio is the most widely used medium of information delivery in rural Africa (Hudson et al., 2017). Fig. 1 also indicates that 32% and 23% of the households respectively in Rwanda and Uganda received safe pesticide use information via more than one campaign channel. However, only 7% and 4% of the households received information through all the three channels used in the campaigns in the two countries, respectively.

Table 2 compares the unconditional mean outcome values for information recipients and non-recipients in the two study countries. We find that the information recipients in Rwanda outscored the non-recipients on pesticide safety knowledge test by about 6 percentage points, which is significant at the 1% level. Similarly, in Uganda, the information recipients outperformed their non-recipient counterparts on the knowledge test by roughly 7 percentage points. The descriptive results also show that in both countries, a significantly higher proportion of information recipients than non-recipients used synthetic pesticides for FAW control. In addition, the information recipients adopted one more non-chemical pest management method than the non-recipients. Among the popular non-chemical measures used include timely planting, regular monitoring of maize plants to scout for FAW, rotation with non-host plants and handpicking of larvae (Figure A1 in the appendix). Less than 5% of the household used natural enemies and home-made biopesticides for FAW control. Generally, a greater share of the respondents in Rwanda than in Uganda implemented multiple non-chemical FAW control strategies. This may be reflective of differences in prior knowledge of FAW management practices, given that the Rwanda survey was conducted four years after the outbreak of the pest in the country, while the Uganda data were collected around the onset of FAW invasion.

Table 2 also shows that the households in Uganda performed slightly better on the knowledge tests than those in Rwanda, which could be due to differences in level of education (Table 1) or the channels used in conveying the campaign messages (Fig. 1). On the other hand, a relatively higher share of households in Rwanda use synthetic pesticides and IPM practices, and wear protective gears while spraying pesticides than their counterparts in Uganda. Consequently, more pesticide-related health problems were reported by households in Uganda than in Rwanda. We also observe that the information recipients use multiple PPE items when spraying pesticide than the non-recipients, but the mean difference is only statistically significant in the case of Rwanda.

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[3] The three steps of the doubly robust method are jointly estimated using the *teffects ipwra* command in stata.

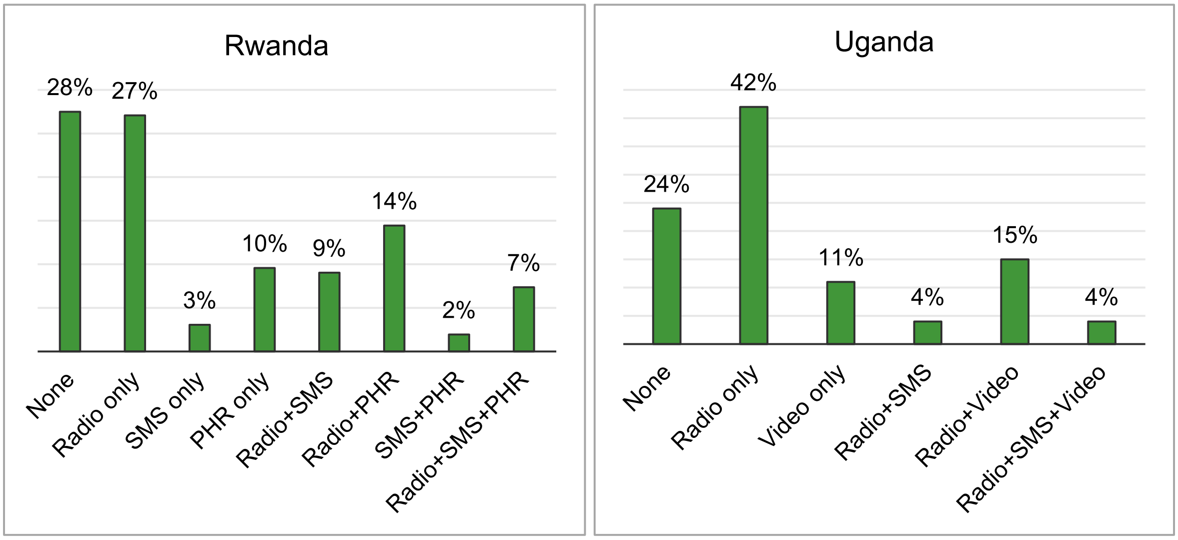

Fig. 1. Percentage of households that received safe pesticide use information via the campaign channels. Note: n in Rwanda = 720; n in Uganda = 607.

Table 2
Summary statistics for outcome variables.

Outcome variable	Rwanda		Uganda	
	Recipients (n = 522)	Non-recipients (n = 198)	Recipients (n = 460)	Non-recipients (n = 147)
Pesticide knowledge score (%)	77.20***	71.31	82.65***	75.78
Use of synthetic pesticides (1/0)	0.86***	0.71	0.80***	0.60
Use of non-chemical methods (#)	5.09***	4.02	3.61***	2.23
Use of PPE items (#)	2.22***	1.82	1.65	1.41
Acute pesticide symptoms (#)	0.51	0.57	1.08	0.84

Note: *** denotes that the mean difference between information recipients and non-recipients is significant at the 1% level.

The types of pesticides used by the households for controlling FAW are presented in Table 3. A clear majority of households used Rocket, which is an approved pesticide for FAW control in both countries. Rocket contains the active ingredients Profenofos and Cypermethrin, which are also found in other pesticides used in Uganda, such as Dudu Fenos, Larvet and Supa profenofos. Most of the pesticides used are moderately hazardous, according to the World Health Organization's recommended classification of pesticides by hazard (WHO 2020). We also see a few cases of the use of restricted, wrong or highly toxic pesticides. In Rwanda, for instance, a few households (particularly the non-information recipients) used Endosulfan, which is a banned pesticide in the country. Moreover, three households sprayed Metalaxyl-M, which is a fungicide even though FAW is not a fungus. In Uganda, about 2% of the information recipients used Dichlorvos, which although not restricted in the country, is a highly hazardous pesticide. Surprisingly, none of households in the two countries used a commercially produced biopesticide, which is considered a safer option and is highly recommended for FAW control (Day et al., 2017; Bateman et al., 2018). This is possibly due to lack of availability, which is a common challenge for biopesticide usage among African smallholders (Constantine et al., 2020).

Table 3
Types of pesticides used for FAW control in Rwanda and Uganda.

Country	Trade name	Active ingredient	WHO toxicity class[a]	Recipients	Non-recipients
Rwanda (n = 590)	Rocket	Profenofos + Cypermethrin	II	95.55**	90.78
	Thiodan	Endosulfan	II	1.11***	4.96
	Cypermetrin	Cypermethrin	II	3.34	1.42
	Lambda	Lambda-cyhalothrin	II	0.89	0.00
	Ridomil	Metalaxyl-M	II	0.67	0.00
	Sumicombi	Fenitrothion + Fenvalerate	II	0.67	0.00
Uganda (n = 455)	Rocket	Profenofos + Cypermethrin	II	76.02	72.73
	Striker	Lambda-cyhalothrin + Thiamethoxam	III	26.98*	17.05
	Dudu Fenos	Profenofos + Cypermethrin	II	12.81	11.36
	Larvet	Profenofos + Cypermethrin	II	7.90	4.55
	Supa profenofos	Profenofos + Cypermethrin	II	6.81	9.09
	Profecron	Profenofos + Cypermethrin	II	3.27	1.14
	Ambush	Cypermethrin	II	1.91**	5.68
	Dudu-Cyper	Cypermethrin	II	1.36	1.14
	Lava	Dichlorvos	Ib	2.18	0.00
	Umeme	Lambda-cyhalothrin	II	1.91	0.00

Note: ***, ** and * indicate that the mean difference between information recipients and non-recipients is significant at the 1%, 5% and 10% level, respectively.

[a] Ia = extremely hazardous; Ib = highly hazardous; II = moderately hazardous; III = lightly hazardous; U = unlikely to present acute hazard; N = not classified (WHO 2020).

Fig. 2 compares the use of PPE items among information recipient and non-recipient households across the two countries. The results reveal some interesting patterns. First, a higher share of information recipients wore standard PPE items than the non-recipients, and this is particularly noticeable in the Rwanda sample. With the exception of the use of gloves in Uganda, proportionally more information recipients use the PPE items than the non-recipients in both countries. Second, only about a quarter of the pesticide users in Uganda wore mask while

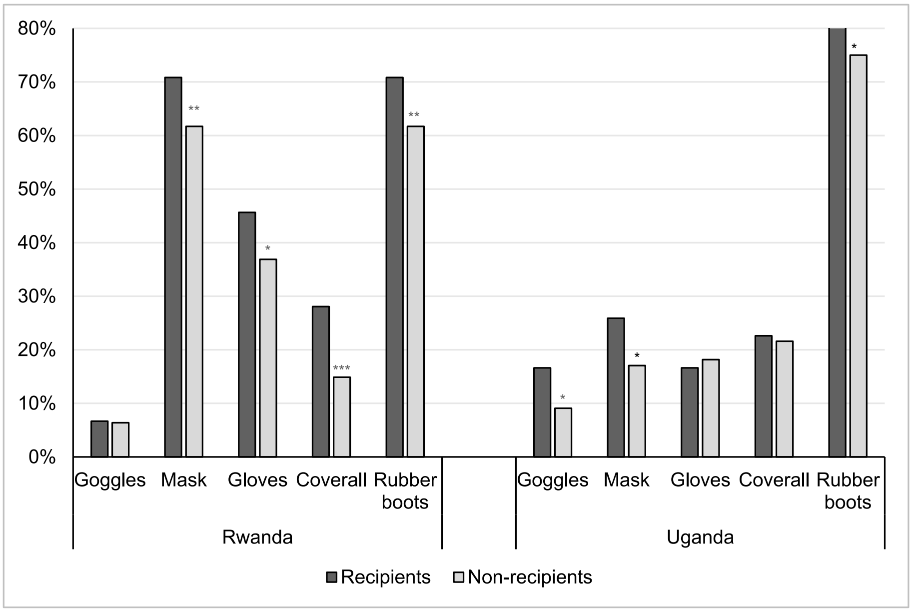

Fig. 2. Percentage of users of PPE items
Note: ***, ** and * indicate that the mean difference between information recipients and non-recipients is significant at the 1%, 5% and 10% level, respectively.

spraying pesticides, compared to more than two-thirds of their counterparts in Rwanda. In other words, the percentage of mask users in Rwanda are about three times those in Uganda. This is likely because the Uganda survey was conducted in 2018 (pre-Covid period), while the Rwanda survey occurred during a period of increased supply of masks due to the Covid-19 outbreak. This is an important finding, given previous evidence that many smallholders in the two study countries and elsewhere do not often use PPE items while working with pesticides, which is partly attributed to inaccessibility (Okonya and Kroschel 2015; Ndayambaje et al., 2019; Andersson and Isgren 2021; Tambo et al., 2021).

In total, only 13% and 8% of the pesticide users in Rwanda and Uganda, respectively, wore full protective clothing while mixing and applying pesticides. This is alarming, given that most of the pesticides used are moderately toxic (as shown in Table 3), which can have adverse health effects. Hence, it is unsurprising that some of the pesticide users (17% in Rwanda and 50% in Uganda) have reportedly suffered ill-health from pesticide exposure. The most common pesticide-related health symptoms reported include headache, sneezing, fatigue and eye irritation (Table A1 in the appendix).

Table 4
Information effects on pesticide safety knowledge and practices.

Outcome	Rwanda			Uganda		
	ATET	Robust SE	ATET in %	ATET	Robust SE	ATET in %
Pesticide knowledge score (%)	4.57**	2.20	6.29	5.18*	2.75	6.69
Use of synthetic pesticides (1/0)	0.09***	0.03	11.69	0.03	0.03	3.90
Use of non-chemical methods (#)	1.09***	0.15	27.25	1.09***	0.23	43.25
Use of PPE items (#)	0.35**	0.14	18.82	0.26*	0.14	18.84
Acute pesticide symptoms (#)	−0.47**	0.22	−47.96	−4.81	12.99	−81.66

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. The ATET in % values are the percentage gains over the potential-outcome means of the non-recipients.

3.2. Effects of information campaigns

Before focussing on the doubly robust estimation results on the effects of the mass media campaigns, we first check if the estimated models pass some necessary diagnostic tests. Figure A2 in the appendix shows sufficient overlaps in the covariate distributions of the recipients and non-recipients of the pesticide information, thus suggesting a non-violation of the overlap or common support condition (Imbens et al. 2004). In addition, the balance diagnostic test results in Table A2 in the appendix show insignificant chi-squared statistics, indicating that the first step of the doubly robust model successfully balanced the covariates by weighting (Imai and Ratkovic 2014).

Table 4 shows that the information interventions are significantly associated with improved knowledge of pesticide risks and safety precautions in the two study countries. In particular, the information recipients scored 5 percentage points (or 6–7%) higher on the pesticide knowledge test questions. Examining the results for the five individual knowledge questions (Table A3 in the appendix), we find that the information campaign in Rwanda is significantly correlated with 17% and 13% improved farmer knowledge of the health and environmental risks of pesticides, respectively. In Uganda, the campaign is significantly associated with increased knowledge about the environmental risks of pesticides by 6%, and the importance of PPE and disposal of empty pesticide containers by about 7%. The results in Table A3 also suggest that the campaigns in both countries did not exert significant effects on farmer knowledge concerning pre-harvest interval. It is possible that there was limited content on pre-harvest interval in the campaign messages or this topic is not fully understood when delivered through mass media channels.

The estimation results in Table 4 further show that the information campaigns are positively correlated with the use of synthetic pesticides, but the treatment effect estimate is only significant in the case of Rwanda. On the other hand, the campaigns significantly influenced the adoption of non-chemical pest management practices in both countries. Specifically, the information recipients applied one additional non-chemical control strategy compared to the non-recipients. Put differently, households that received the campaign messages in Rwanda and Uganda are respectively 27% and 43% more likely than their non-recipient counterparts to adopt multiple alternatives to synthetic pesticides. Thus, while the information recipients have a higher likelihood of using synthetic pesticides to combat the devastating FAW pest, they are more likely to combine it with multiple non-chemical strategies, in line with the objectives of the mass media campaigns and the tenets of IPM. This is encouraging, given that IPM is considered the preferred approach to sustainable FAW control (Day et al., 2017). This finding also lends support to arguments that poor access to IPM information is a fundamental constraint to widespread adoption among developing-country farmers (Parsa et al., 2014; Alwang et al., 2019).

We also find that in both countries, the receipt of pesticide safety information is significantly associated with nearly 19% higher likelihood of a farmer using multiple PPE items when spraying pesticides. This is noteworthy because the wearing of protective clothing can limit the negative health effects of pesticides, especially considering that the pesticides used against FAW are hazardous to human health. This also implies that the mass media campaigns may have contributed to addressing the information constraints associated with limited PPE use (Ndayambaje et al., 2019; Tambo et al., 2021), thereby inducing farmers to wear protective gears while working with pesticides. Finally, Table 4 indicates that the information campaigns are significantly correlated with a 48% reduction in the probability that a pesticide user in Rwanda will experience multiple pesticide-related symptoms. We also observe a negative but insignificant effect of the campaigns on pesticide-induced illness in Uganda.

Table 5 reports the PSM results using the kernel matching method.[4] We see that the results in terms of signs and statistical significance of the ATET estimates are qualitatively similar to those obtained using the doubly robust method. For example, similar to the results in Table 4, Table 5 shows that the mass media campaigns are significantly associated with improved farmer knowledge of pesticide safety, higher adoption of alternatives to synthetic pesticides and increased use of PPE items in Rwanda and Uganda. The results of the Rosenbaum bounds sensitivity analysis on hidden bias (Γ) suggest that the ATET estimates are generally not sensitive to unobserved heterogeneity or hidden bias (Rosenbaum 2002).

3.3. *Differential effects of information channels*

In this section, we explore whether the observed significant effects of the information campaigns on farmer knowledge of pesticide hazards and adoption of safety measures differ by the type and number of channels.[5] The doubly robust estimation results for Rwanda show that while the campaign has a positive effect on knowledge outcomes, the effect is only statistically significant for households who received the information through multiple channels (Table 6). This is unsurprising as multiple channels repeat and reinforce the campaign messages, thereby enabling a better understanding of the messages. We also see that the knowledge gains are slightly larger when the information is received through multiple channels that include SMS. For instance, the knowledge increases due to exposure to Radio + PHR is about 5 points or 7%, while that due to exposure to Radio + SMS is about 9 points or 12%, as compared to non-recipients. This is possibly because messages received via SMS can be kept for later reference and used as reminders.

The results in Table 6 indicate that the adoption of synthetic pesticides for FAW control is significantly influenced by the receipt of information via multiple campaign channels, but not through single channels. The campaigns in Rwanda are also significantly associated with increased adoption of non-chemical pest management practices, irrespective of the type of information channel used or whether the information was received from a single or multiple source(s). However, the ATET estimates are larger for the combined channels, with the concurrent exposure to the three channels (Radio + SMS + PHR) producing the greatest effect. Similarly, the three channels in combination have the highest effect in terms of stimulating the use of PPE items and reducing the incidence of pesticide-related illness. Interestingly and logically, the channels that significantly influence the use of PPE items are also those that are significantly associated with lower likelihoods of acute pesticide poisoning symptoms.

Turning to the results for Uganda (Table 7), we find that radio programming, either used as a stand-alone channel or in combination with video screenings, is associated with improved farmer knowledge about pesticide hazards and safety measures. Similar to the Rwanda results, all the campaign channels (whether in isolation or in combination) are significantly associated with increased adoption of multiple alternatives to pesticides. Table 7 further shows that a significant increase in PPE usage is obtained when households receive the information through both radio and video, but not through the two channels singly. We find negative but insignificant effects of the channels on pesticide-related illness, which corresponds to the aggregated results for Uganda in Table 4. Consistent with the Rwanda results, we observe that the significant effects of the campaigns on our outcome variables are more pronounced for Ugandan households who received the pesticide information via multiple channels. This is likely because repeated exposure to the same information from different media sources reinforces the information, making it memorable and instructive.

4. Discussion

The study results suggest that the mass media campaigns have played a significant role in improving pesticide knowledge and in promoting the adoption of environmentally-friendly pest management practices among smallholder farmers in the two study countries. Our findings are generally consistent with previous evidence on the positive role of information and training interventions, such as farmer field schools (Waddington et al., 2014), farmer training (Schreinemachers et al., 2016; Gautam et al., 2017; Goeb and Lupi 2021) and plant clinics (Tambo et al., 2021) in improving farmer knowledge and adoption of pesticide safety and IPM practices. In addition, our findings demonstrate that greater outcomes were achieved by those who were exposed to repeated messages from multiple mass media channels. This is an important finding because the proliferation of ICTs in developing countries can allow the dissemination of information to a wide range of farmers through mass media campaigns, thereby complementing the efforts of traditional face-to-face information delivery methods.

In line with previous studies in Bangladesh (Schreinemachers et al., 2016) and Rwanda and Zambia (Tambo et al., 2021), we found that the information interventions are associated with an increase in the likelihood of a household using synthetic pesticides in Rwanda. The campaigns were implemented in the wake of the FAW pest outbreak, which was causing serious damages to maize production in the two countries and beyond. Hence the use of pesticides for controlling the pest was unavoidable in the short term, and was actually promoted as a last resort as part of IPM package. Moreover, several studies have shown that the FAW invasion has spurred increased and indiscriminate use of pesticides among many smallholders in Africa and Asia (Tambo et al., 2020; Yang et al., 2021). Hence, the campaigns stressed on rational use of pesticides, including using recommended pesticides in combination with non-chemical pest control methods, as well as using PPE and pesticide safety practices. It is encouraging to find that the campaigns are associated with the use of non-chemical IPM practices and PPE in both

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[4] We find consistent results using alternative matching algorithms, such as nearest neighbour and radius matching. For a good overview of PSM and the different matching methods, see Caliendo and Kopeinig (2008).

[5] Given the low percentage of households exposed to SMS only and SMS + PHR in Rwanda as well as Radio + SMS and Radio + SMS + Video in Uganda (see Fig. 1), these options are excluded from the disaggregated analysis.

Table 5
Kernel matching estimates of information effects.

Outcome	Rwanda				Uganda			
	ATET	SE	ATET in %	Γ	ATET	SE	ATET in %	Γ
Pesticide knowledge score (%)	4.45**	2.15	6.12	1.20–1.30	6.55**	2.66	40.92	2.20–2.30
Use of synthetic pesticides (1/0)	0.12***	0.04	16.22	2.40–2.50	0.03	0.06	3.90	–
Use of non-chemical methods (#)	1.03***	0.15	25.43	2.60–2.70	1.22***	0.22	50.83	3.70–3.80
Use of PPE items (#)	0.37***	0.13	20.00	1.90–2.00	0.34*	0.18	25.95	2.00–2.10
Acute pesticide symptoms (#)	−0.33*	0.17	−39.29	2.90–3.00	0.29	0.18	35.80	–

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. The ATET in % values are the percentage gains over the potential-outcome means of the non-recipients. Γ = critical level of hidden bias.

Table 6
Differential effects of information channels in Rwanda.

Outcome	Radio	PHR	Radio + SMS	Radio + PHR	Radio + SMS + PHR
Pesticide knowledge score (%)	4.00	1.00	8.66**	4.86*	6.82*
	(2.58)	(3.42)	(3.78)	(2.92)	(3.55)
	5.50%	1.39%	12.14%	6.60%	9.52%
Use of synthetic pesticides (1/0)	0.07	0.06	0.13***	0.12***	0.18***
	(0.04)	(0.06)	(0.05)	(0.05)	(0.04)
	9.21%	8.22%	16.88%	15.19%	21.95%
Use of non-chemical methods (#)	0.75***	0.89***	1.50***	1.05***	1.99***
	(0.19)	(0.30)	(0.28)	(0.21)	(0.33)
	18.61%	22.47%	37.50%	26.45%	49.63%
Use of PPE items (#)	0.31*	0.16	0.54**	0.24	0.66**
	(0.17)	(0.23)	(0.24)	(0.18)	(0.29)
	16.40%	8.79%	28.57%	12.83%	33.67%
Acute pesticide symptoms (#)	−0.62**	0.05	−0.68**	−0.24	−0.88**
	(0.28)	(0.21)	(0.32)	(0.25)	(0.42)
	−53.91%	13.16%	−56.64%	−28.92%	−60.28%

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. The % values are the percentage gains over the potential-outcome means of the non-recipients.

Table 7
Differential effects of information channels in Uganda.

Outcome	Radio	Video	Radio + Video
Pesticide knowledge score (%)	6.59**	1.07	8.46**
	(3.19)	(3.70)	(3.30)
	8.69%	1.33%	10.84%
Use of synthetic pesticides (1/0)	0.01	−0.06	0.05
	(0.04)	(0.08)	(0.04)
	1.27%	9.84%	6.25%
Use of non-chemical methods (#)	1.06***	0.85***	1.25***
	(0.25)	(0.31)	(0.34)
	44.35%	34.00%	46.47%
Use of PPE items (#)	0.05	0.24	0.55***
	(0.18)	(0.25)	(0.21)
	3.33%	21.82%	45.08%
Acute pesticide symptoms (#)	−7.01	−0.57	−0.12
	(20.51)	(1.32)	(0.67)
	−86.97%	−31.67%	−10.00%

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. The % values are the percentage gains over the potential-outcome means of the non-recipients.

countries, and only few (2%) of the pesticide users applied highly hazardous pesticides. The use of pesticides is not necessarily bad, but given the poor pesticide practices among smallholder farmers, emphasis should be put on promoting lower-risk pesticide products, such as biopesticides.

We note that our analysis has focused on the effects of mass media campaigns on whether households applied pesticides or not (extensive margin), but not on the amount of pesticides used (intensive margin). A previous study conducted in Rwanda and Zambia showed that while the provision of plant health advisory services to FAW-affected farmers led to an increase in the probability of using pesticides, it did not lead to intensification of pesticide use (Tambo et al., 2021). In future studies, it would be interesting to also investigate pesticide use intensity, which was not possible in the current study due to data limitations. In addition, given that some of the non-chemical IPM practices are long-term pest management strategies, there is a need for follow-up studies to examine whether the observed positive effects of the campaigns on IPM adoption will translate into reduced pesticide use in the near future, particularly given that pesticides will likely remain a dominant method of pest management in the face of intensifying pest infestations (Williamson et al., 2008; Andersson and Isgren 2021). This can also help address concerns about the sustainability of behavioural change achieved through safe pesticide use campaigns (Murray and Taylor 2000).

While our findings and those of other studies suggest that information interventions can generate some positive outcomes in terms of knowledge increase, sustainable pest management and safe pesticide use, it should be mentioned that there is also good evidence that information and knowledge about pesticide risks and safety precautions do not necessarily translate into safe pesticide use outcomes (e.g., Murray and Taylor 2000; Galt 2013; Goeb et al., 2020). The differing effects of information across studies could be due to several factors, such as: who initiated and implemented the campaign (collaborative approach and NGO-led initiative as part of an agricultural development programme versus pesticide industry's safe use campaigns); the information channels used (traditional face-to-face versus complementary ICT-mediated channels); the design and focus of the campaign (e.g., the campaigns studied here focused broadly on sustainable pest management approaches rather than on pesticides only and were designed to tackle the outbreak of a new and an important invasive pest, which had triggered widespread use of pesticides among smallholder farmers); as well as other contextual factors.

It should also be emphasised that while information is a necessary part of a pesticide safety behavioural change campaign, it is not sufficient for behavioural change. There is a growing body of literature showing that farmers' pesticide use and risky pesticide practices are driven by a plethora of interacting factors, including knowledge deficit, input market liberalization, aggressive marketing by the pesticide industry, ecological and socio-economic conditions in the farming area, regulatory failures related to the types of pesticides entering countries and occupational safety, perceptions of safety and quality, the persistent neglect of agricultural extension, a lack of policy support for less pesticide-intensive farming, among other factors (Murray and Taylor 2000; Galt 2014; Ngowi et al., 2016; Andersson and Isgren 2021; Isgren and Andersson 2021; Shattuck, 2021; Stein and Luna 2021; Young et al., 2022). Thus, the benefits from safe pesticide use campaigns will not be maximised without considering these structural conditions that shape the choice of crop protection strategies and pesticide use practices.

5. Conclusions

In this paper, we tested the assumption that mass media campaigns can help improve pesticide knowledge and safety practices among smallholder farmers. We also assessed the relative effectiveness of different information channels in achieving pesticide safety outcomes. We used survey data from 1327 smallholder maize-producing households in Rwanda and Uganda, where multiple mass media channels have been used to disseminate consistent and accurate advice on pesticide safety and sustainable crop protection strategies to farmers.

Results from a doubly robust estimator showed that the mass media campaigns are significantly associated with improved farmer knowledge of pesticide risks and safety precautions, including knowledge about health and environmental risks of pesticides, and the importance of PPE use. We also found that while the campaigns did not lead to a reduction in synthetic pesticide use (particularly in Rwanda), it is significantly associated with increased adoption of safer alternatives to pesticides. Specifically, households that received the campaign messages in Rwanda and Uganda are respectively 27% and 43% more likely than their non-recipient counterparts to use a combination of different non-chemical pest management strategies, such as regular scouting of crops for pests, crop rotation, field sanitation and handpicking to combat the highly destructive FAW pest. These results are robust to using matching methods.

We found evidence of limited use of biopesticides, widespread use of moderately toxic pesticides, and a few cases of the misuse of pesticides for FAW control. We also found limited use of protective equipment against pesticide exposure, which is troubling. For instance, less than a third of the households in Uganda used goggles, mask, gloves and coverall while mixing and applying pesticides. As a result, some pesticide-using farmers (up to 50% in Uganda) reported to have suffered acute pesticide illnesses, such as headache, sneezing, fatigue and eye irritation in just one agricultural season. Encouragingly, our analysis showed that the receipt of pesticide safety information is significantly associated with almost 20% higher likelihood of using multiple PPE items while spraying pesticides in both countries. In addition, the information recipients in Rwanda were 48% less likely than their non-recipient counterparts to experience a pesticide-related health symptom. We also found that the positive the effects of the campaigns are more pronounced for households who received the information via multiple channels, pointing to complementary effects of the channels. In Rwanda, for instance, the likelihood of adopting multiple IPM practices increases by about 19%, 38% and 50% when the information is received through Radio only, Radio + SMS and Radio + SMS + PHR, respectively.

Overall, our findings imply that mass media campaigns can be effective in enhancing knowledge about pesticide risks and safety precautions and promote the adoption of certain pesticide safety practices (such as PPE usage) and environmentally-friendly crop protection practices (such as IPM) among smallholder farmers. Moreover, the campaigns can be especially effective when multiple digital advisory services are used to reinforce the messages or when the ICT-based channels are complemented with low-cost in-person extension services, such as plant health rallies. Our findings also highlight other actions needed to improve pesticide safety practices in the study countries besides information interventions. For instance, given the increased use of toxic synthetic pesticides without or with limited protective equipment, policy efforts are needed to increase the supply and use of lower-risk pesticides such as biopesticides, alongside the promotion of PPE use to reduce the risk of pesticide exposure. Such efforts could include improving the registration of biopesticide products and providing subsidies to spur adoption, as highlighted by previous research (Grovermann et al., 2017; Bateman et al., 2018; Day et al., 2022).

Finally, a few limitations of this study should be mentioned. First, we used observation data and selection-on-observable estimators, which precluded us from providing causal interpretations of our findings. Second, there is a possibility of spillover of information from the recipients to the non-recipients of the campaign messages, which can result in a downward bias in the ATET estimates. Future research could use experimental designs to properly control for potential unobserved heterogeneity bias and test our findings. The use of experimental designs can also help to detect and account for spillover effects (Wilke et al., 2020; Vandevelde et al., 2021). Third, while we have shown that multiple information channels lead to greater positive outcomes than single channels, using multiple channels has cost implications. It would be interesting to explore if the incremental gains from additional channels are worthwhile in terms of cost-effectiveness.

Credit author statement

Justice A. Tambo: Conceptualization, Methodology, Formal analysis, Writing- Original draft preparation, Writing - Review & Editing, Supervision. Idah Mugambi: Data curation, Software, Writing - Review & Editing. **David O. Onyango:** Investigation, Writing - Review & Editing. **Bellancile Uzayisenga**: Investigation, Writing - Review & Editing, Supervision. **Dannie Romney:** Writing - Review & Editing, Funding acquisition, Project administration.

Declaration of interest statement

Justice A. Tambo, Idah Mugambi, David Onyango and Dannie Romney are employed at CABI, the institution that manages the Plantwise programme, which funded the implementation of the mass media campaigns.

Data availability

Data will be made available on request.

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Appendix

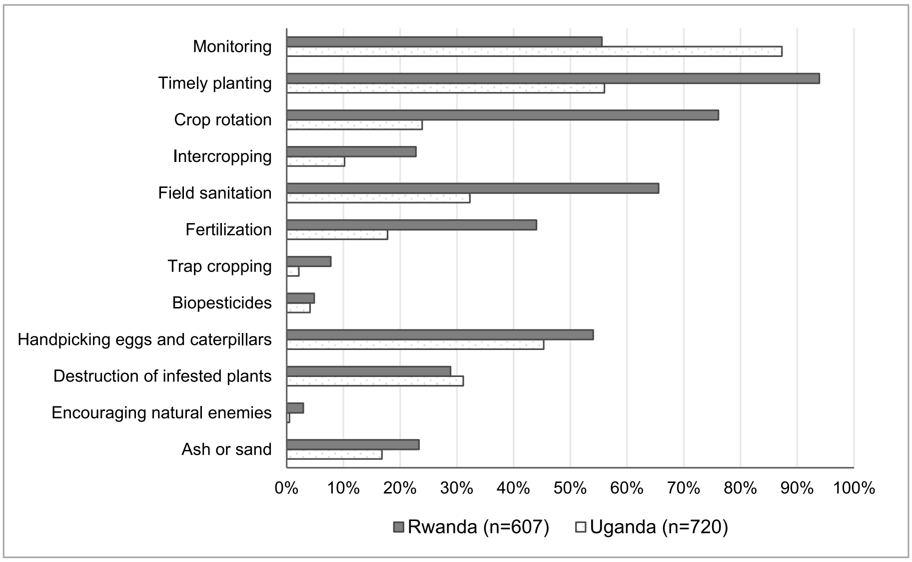

Fig. A1. Non-chemical FAW management measures used by households

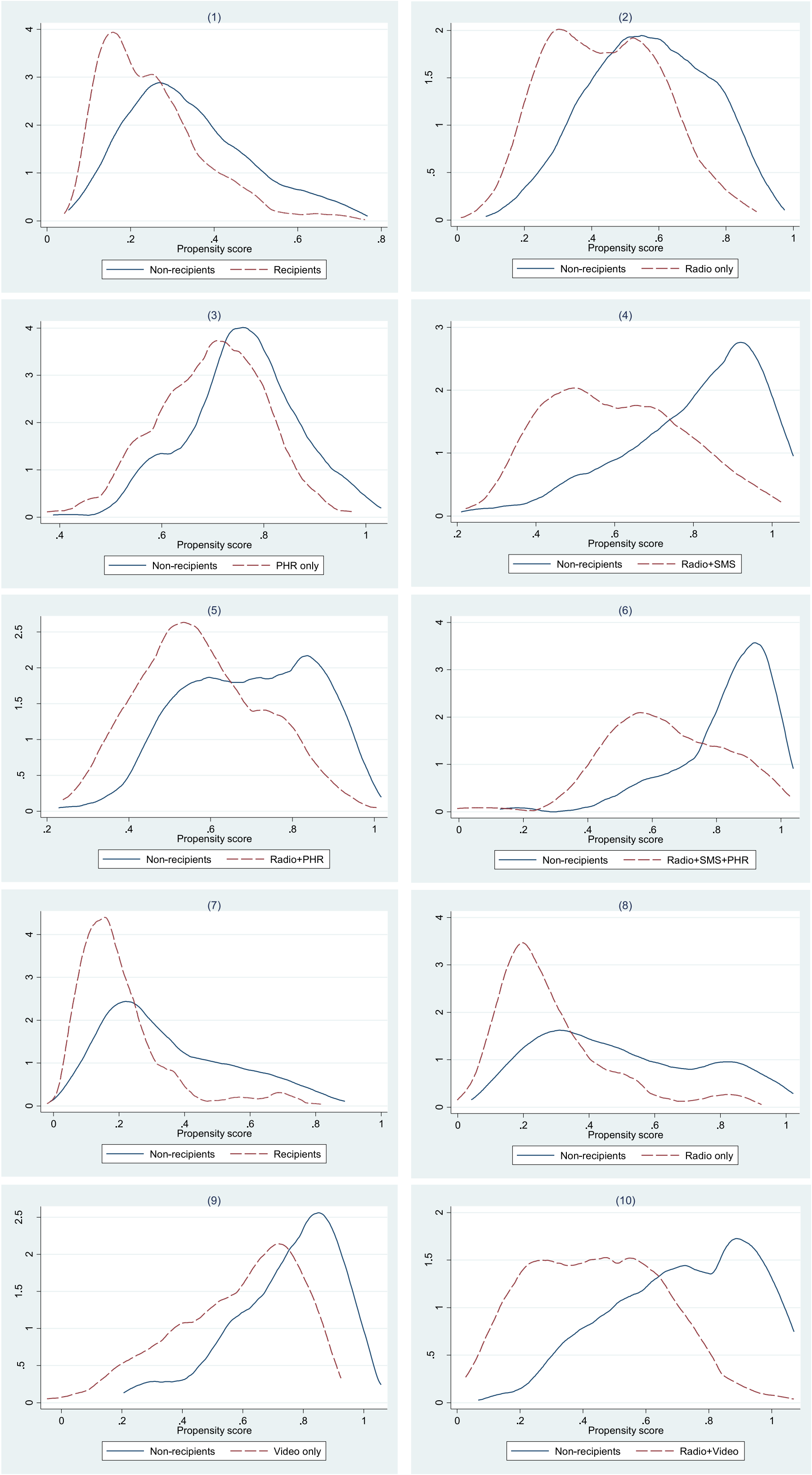

Fig. A2. Overlap plots. Plots 1–6 and 7–10 are for Rwanda and Uganda, respectively.

Table A1
Acute pesticide-related health symptoms experienced

Symptom	Rwanda (n = 590)	Uganda (n = 455)
Headache	11.53	15.38
Sneezing	9.83	18.46
Nausea/vomiting	2.03	3.96
Stomach cramps	1.19	4.40
Fatigue	6.44	8.79
Skin rash/irritation	7.46	2.66
Dizziness	2.20	5.93
Blurred vision	2.54	2.42
Diarrhoea	0.00	1.10
Eye irritation	7.23	13.19
Excessive sweating	1.86	1.10
Excessive coughing	0.00	1.54

Table A2
Covariate balancing test

Treatment level	Chi2	P-value
Rwanda		
Recipients vs. non-recipients	10.97	0.7544
Radio only vs. non-recipients	14.05	0.5219
PHR only vs. non-recipients	6.99	0.9579
Radio + SMS vs. non-recipients	14.24	0.5077
Radio + PHR vs. non-recipients	9.72	0.7164
Radio + SMS + PHR vs. non-recipients	15.33	0.2871
Uganda		
Recipients vs. non-recipients	16.16	0.4421
Radio only vs. non-recipients	14.20	0.5837
Video only vs. non-recipients	16.30	0.4324
Radio + Video vs. non-recipients	9.22	0.9043

Table A3
Information effects on knowledge outcomes

Knowledge outcome	Rwanda			Uganda		
	ATET	Robust SE	ATET in %	ATET	Robust SE	ATET in %
Health risks of pesticides (1/0)	0.12***	0.04	16.67	0.05	0.04	6.94
Environmental risks of pesticides (1/0)	0.09**	0.04	13.04	0.11**	0.05	15.71
Importance of PPE (1/0)	0.03	0.03	3.48	0.06**	0.03	6.74
Re-use of pesticide containers (1/0)	0.05	0.04	6.17	0.06*	0.04	7.39
Pre-harvest interval (1/0)	−0.05	0.05	−9.09	−0.07	0.04	−8.75

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. The % values are the percentage gains over the potential-outcome means of the non-recipients.

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