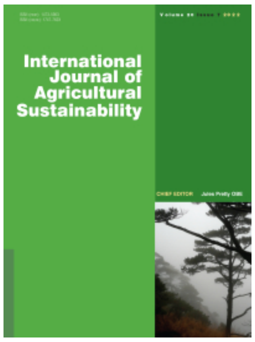

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The role of agro-input dealer certification in promoting sustainable pest control: insights from Uganda

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ABSTRACT

Pesticides are crucial for increasing agricultural productivity, but they have also been linked to a range of health and environmental risks. In this paper, we used nationally representative data from 557 agro-dealers in Uganda to assess the role of agro-dealer certification in improving knowledge and practices related to environmentally-friendly pest control. We found that almost half of the sampled agro-dealers were not certified or accredited by regulatory bodies, even though this is a prerequisite for selling pesticides in the country. Results further showed that only 16% of the agro-input shops were selling biopesticide products, largely due to a lack of awareness, access and demand from farmers. Regression results showed that certified agro-dealers were 9–12 percentage points more likely to know about biopesticides and integrated pest management, and 8–10 percentage points more likely to sell biopesticide products, compared to their non-certified counterparts. Our findings imply that agro-dealer certification courses can play an important role in raising knowledge and stimulating the supply of environmentally-benign pest control products. We identified regulatory enforcement, a decentralized certification system and agro-dealer associations as some of the potential pathways for incentivising compliance with certification requirements, thereby promoting lower-risk pest control products and strategies.

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Agro-input dealers; certification; biopesticides; integrated pest management; Uganda

1. Introduction

The use of pesticides-such as fungicides, herbicides and insecticides – in agriculture has increased dramatically in recent decades (FAOSTAT, 2022). This has been driven by intense pest pressure, pesticide subsidies, lack of advice on alternative methods, among other factors (Williamson et al., 2008). While pesticides are crucial for increasing agricultural productivity and food security (Popp et al., 2013; Sheahan et al., 2017), they have also been linked to a range of negative externalities, including biodiversity loss, soil and water pollution, food contamination, acute and chronic health problems, and poisoning of pollinators and natural enemies (Berni et al., 2021; Kim et al., 2017; Rani et al., 2021; Sheahan et al., 2017). To reduce these health and environmental risks associated with pesticides, farmers need information on the safe use of crop protection products and alternatives to broad-spectrum insecticides, such as biopesticides and integrated pest management (IPM) (Constantine et al., 2020; Deguine et al., 2021).

Agricultural extension agents are an important source of information on pest and pesticide management, but they have limited capacity to reach out to and serve many farmers (Anderson & Feder, 2007; Piñero et al., 2018). For instance, only an estimated 22% of farmers in Uganda are covered by the public extension system (MAAIF, 2016). Hence, many

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smallholder farmers rely on agro-input dealers (simply called agro-dealers) not only as a source of farm inputs but also for pest management information, and this role has become particularly important given the increased demand for pesticide products (Diemer et al., 2020; Sones et al., 2015). Unfortunately, agro-dealers tend to lack the prerequisite training and technical knowledge to be able to provide appropriate advice on IPM and safe pesticide handling practices (Kwakye et al., 2019; Lekei et al., 2014; Schreinemachers et al., 2015). They may have conflicts of interest when providing advice that might affect product sales. Many of them also engage in poor pesticide practices, including sales of fraudulent products (Haggblade et al., 2021; Staudacher et al., 2021).

In an effort to address these challenges and promote sustainable pest and pesticide management, pesticide regulatory authorities in many countries have established mandatory agro-dealer certification schemes, which require agro-dealers to be trained and certified in judicious pesticide use, sustainable IPM solutions and related topics (Holmes & Ogunmodede, 2023; Mengistie et al., 2015; Staudacher et al., 2021). Yet, research on the potential role of agro-dealer certification in promoting sustainable pest management is lacking. As emphasized by Haj-Younes et al. (2015) and Wiedemann et al. (2022), there is generally little research on agro-dealers, despite their importance in the pesticide supply chain. Most empirical studies on safe use of agricultural pesticides in the Global South tend to focus on the practices and knowledge of farmers (e.g. Andersson & Isgren, 2021; Constantine et al., 2020; Mengistie et al., 2017; Okonya & Kroschel, 2015), as well as the effectiveness of training and advisory services in changing pesticide use behaviour (e.g. Clausen et al., 2017; Dunn et al., 2023; Goeb & Lupi, 2021; Tabe-Ojong et al., 2023; Tambo et al., 2021; Tambo et al., 2023). The few studies examining agro-dealers have also focused largely on knowledge, attitudes and practices (e.g. Bhandari et al., 2018; Lekei et al., 2014; Staudacher et al., 2021), while the determinants and implications of agro-dealer certification remain unexplored in the literature.

We contribute to filling this gap in the literature by investigating agro-dealers' compliance with mandatory certification requirements and its implications for improving knowledge and practices related to environmentally-friendly pest control. Specifically, this study aims to: (1) examine the characteristics of agro-dealers and their shops, especially in relation to compliance with pesticide regulations in Uganda; (2) understand agro-dealers' knowledge of and attitudes towards environmentally-friendly pest control; and (3) assess the determinants and implications of agro-dealer compliance with a mandatory certification scheme in Uganda. Our study is based on a nationally representative survey of agro-dealers in Uganda, where there is a significant number of both certified and uncertified agro-dealers (Staudacher et al., 2021), thus making it an interesting case to study participation in an agro-dealer certification scheme and its implications. Besides contributing to the academic literature, the findings of this study can be used to inform policies and institutional arrangements aimed at promoting practices that minimize pesticide-related health and environmental risks.

The remainder of the paper is structured as follows. The next section provides a brief overview of agro-dealership in Uganda and describes the study data and estimation methods. Section 3 presents the empirical results, including agro-dealers' characteristics and attitudes towards environmentally-friendly pest control, as well as the determinants and effects of agro-dealer certification. The last section concludes the paper with a summary of key findings and their implications.

2. Materials and methods

2.1. Context and data

In Uganda, the manufacturing, storage, sale and distribution of pesticides are governed by the Agro-Chemicals Control Act of 2006, and regulated by the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). To qualify as an agro-dealer in the country, it is mandatory to have completed at least eleven years of formal education, attended and passed a certification training course on safe use and handling of pesticides, and register with MAAIF. In addition, the shop premises have to be licensed by MAAIF (renewable every two years) and registered with various government agencies (USAID et al., 2016). The five-day training course on safe handling and application of pesticides is offered by MAAIF and Makerere University and is usually held in the capital, Kampala. The topics covered by the course include pest identification and management, pesticides, pesticide regulation, pesticide safety, pesticide effects on human health and the environment, and identification of fake inputs (Kyamanywa et al., 2013).

It is estimated that Uganda has about 3000 agro-dealers who sell various agricultural inputs and provide plant health advice to farmers (Mabaya et al., 2018). However, research has consistently shown that a significant proportion of these agro-dealers have not undergone the mandatory certification course on safe use and handling of pesticides, and are not legally registered with MAAIF (ATU Ltd, 2009; Staudacher et al., 2021). The Department of Crop Inspection and Certification (DCIC) of MAAIF conducts periodic market surveillance to ensure compliance with pesticide regulations, including seizure of counterfeit, substandard or expired products. Nonetheless, violation of pesticide regulations is persistent in the country (Andersson & Isgren, 2021; Tetra Tech, 2018). Pesticide malpractices and pesticide-related illnesses are also prevalent among smallholder farmers in the country (Andersson & Isgren, 2021; Fuhrimann et al., 2022; Okonya & Kroschel, 2015).

The data used in this study came from a nationally representative survey of 557 agro-dealers in Uganda (Figure 1). Agro-dealers are retailers who sell agricultural inputs, such as seeds, fertilizers and pesticides. They work in agro-input shops owned by themselves or others. The survey was conducted in November–December 2021 across all the four administrative regions and 10 sub-regions of Uganda. We purposively selected representative districts in each sub-region based on the MAAIF's estimates of the distribution of agro-input shops across the country. In total, the survey covered 50 out of the country's 136 districts. In each chosen district, between 2–30 agro-input shops were randomly selected proportionate to the density of agro-input shops across the districts. Overall, our sample consists of 182, 152, 87 and 136 agro-input shops from Central, Eastern, Northern and Western regions of Uganda, respectively.

All selected agro-input shops were visited for face-to-face interviews with agro-dealers who regularly attend to customers. The interviews were conducted by a team of 15 local enumerators who were trained by the researchers. The enumerators reached out to 560 agro-dealers, out of which 557 agreed to be interviewed. Data were collected using a tablet-based questionnaire programmed on Open Data Kit platform, which was pre-tested with a sample of agro-dealers in Mukono district. The questionnaire captured information on socio-demographic characteristics of the agro-dealers, shop characteristics, knowledge of and attitudes towards biopesticides and IPM, membership in agro-dealer associations, and participation in Uganda's mandatory certification scheme. In addition to the interviews, the enumerators conducted shop observations to record the types of products sold and to check for regulatory compliance.

2.2. Estimation methods

Before examining the determinants and effects of agro-dealer compliance with certification requirements, we first analyse the characteristics of the agro-dealers and their attitudes towards sustainable pest management strategies. These results are presented descriptively. To explore the factors that influence an agro-dealer's decision to get certified, we specify the following equation:

$$C_i = \beta_0 + \boldsymbol{\beta}_1\boldsymbol{AD_i} + \boldsymbol{\beta}_2\boldsymbol{AS_i} + \varepsilon_i \tag{1}$$

The dependent variable C is a binary variable that takes the value of one if the respondent i has been certified as an agro-dealer by MAAIF; and zero otherwise. ***AD*** is a vector of agro-dealer characteristics, such as age, gender, education level, agrodealership experience, shop ownership status, access to credit and membership in an agro-dealer association. ***AS*** represents a vector of characteristics of an agro-input shop, including whether or not it is licensed with MAAIF and has been inspected by regulatory authorities, as well as distance from the shop to the capital Kampala, nearest competitor and main input supplier. The choice of the explanatory variables is guided by literature on the determinants of agro-dealers' knowledge, beliefs and practices (Bhandari et al., 2018; Staudacher et al., 2021). The βs are parameters to be estimated, and ε is a random error term. We estimate Equation (1) using probit regression, given the binary nature of the dependent variable.

To examine the role of the mandatory agro-dealer certification in promoting environmentally-friendly pest management, the following equation is used:

$$\boldsymbol{Y_i} = \alpha_0 + \alpha_1 C_i + \boldsymbol{\alpha}_2\boldsymbol{AD_i} + \boldsymbol{\alpha}_3\boldsymbol{AS_i} + \mu_i \tag{2}$$

where ***Y*** represents a vector of outcome variables for agro-dealer i. The outcome variables include: (1) whether the agro-dealer knows about IPM; (2) whether the agro-dealer knows about biopesticides; (3) whether the agro-dealer sells biopesticide products. All the three outcome variables are binary indicators that take on a value of one if the agro-dealer (1)

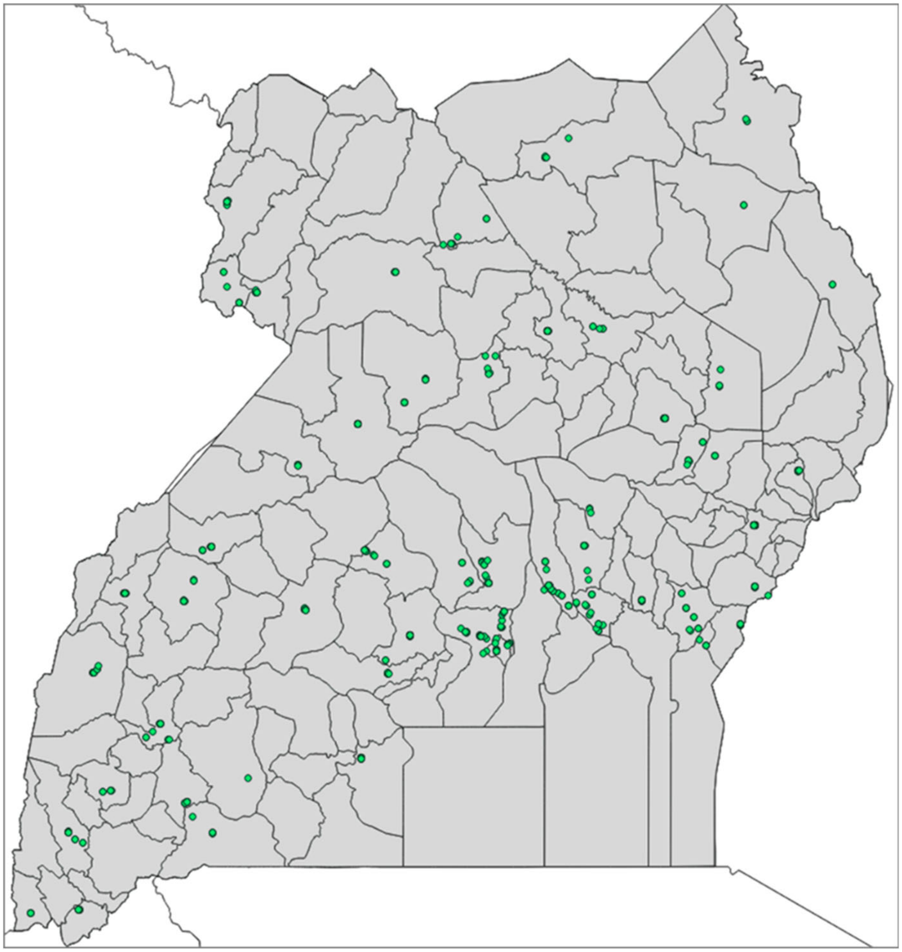

Figure 1. District map of Uganda showing survey locations.

was able to correctly describe IPM; (2) was able to correctly describe biopesticides; and (3) had stocked at least one biopesticide product in the shop at the time of the survey; and zero otherwise. IPM is a crop protection strategy involving the use of a combination of cultural, physical and biological pest control practices, as well as judicious pesticide use, as a last resort (Deguine et al., 2021; Prokopy & Kogan, 2009). Biopesticides include pesticides derived from micro-organisms (algae, bacteria, fungi, viruses), macro-organisms (e.g. predatory and parasitic insects and mites), botanical extracts and secondary metabolites from living organisms (Constantine et al., 2020). The explanatory variables C, $\boldsymbol{AD}$, $\boldsymbol{AS}$ are as defined in Equation (1). α is a vector of coefficients associated with the explanatory variables, and μ is the error term. The main coefficient of interest is α_1, which gives estimates of the effects of agro-dealer certification on our outcomes of interest. We estimate Equation (2) using the multivariate probit model (Cappellari & Jenkins, 2003), which allows us to control for the interdependence between knowledge of IPM and biopesticide and the decision to sell biopesticide products. The model accounts for potential correlation between the three binary outcomes by estimating them jointly (Greene, 2012).

The multivariate probit model in Equation (2) assumes that an agro-dealer's decision to get certified is exogenously given. However, agro-dealer certification is not based on random assignment; hence, it is possible that certified and non-certified adopters may differ systematically in observable and unobservable characteristics that could influence the outcome variables, potentially leading to biased multivariate probit estimates. To reduce this potential bias and as a robustness check, we apply the inverse probability weighted regression adjustment (IPWRA) estimator, in which Equation (2) is weighted by an inverse propensity score computed from Equation 1 (Wooldridge, 2010). The differences in mean outcomes between treated (i.e. certified) and non-certified (i.e. non-certified) agro-dealers are then used to provide estimates of the average treatment effect on the treated (ATET). The ATET quantifies the effect of agro-dealer certification for the certified agro-dealers.

An important advantage of the IPWRA method over other commonly used selection-on-observable estimators, such as propensity score matching (PSM), is its doubly robust property, which states that the ATET estimates would be consistent even if one of the two equations (i.e. Equations 1 and 2) is mis-specified (Imbens & Wooldridge, 2009). However, as a further robustness check, we also use PSM (kernel matching) method (Caliendo & Kopeinig, 2008) to examine the effect of agro-dealer certification.[1] An attractive feature of the PSM method is that it is invariant to functional form assumptions. It should be noted that while the doubly robust and kernel matching methods can account for selection bias due to observable characteristics, they may not be able to correct for potential bias due to unobservable agro-dealer characteristics. We therefore test the robustness of the ATET estimates to unobserved heterogeneity (hidden bias) using the Rosenbaum bound approach of testing the sensitivity for binary-outcome variables (Becker & Caliendo, 2007). Nonetheless, the results from the three regression models (multivariate probit, IPWRA and kernel matching) should be interpreted as associations rather than causal effects.

3. Results and discussion

3.1. Agro-input shops and dealers

The descriptive characteristics of the agro-dealers and shops in our sample are presented in Tables 1 and 2, respectively. Most of the agro-input shops had been in operation for about seven years and had two workers, on average. The average agro-dealer was 33 years of age, with 13 years of formal education and six years of experience in selling agricultural inputs, including pesticides. The sample is evenly divided between agro-dealers who operate their own agro-input shops (i.e. shop owners) and those who run agro-input shops whose owners are absent from the shops (i.e. employees). The sample is also almost equally divided among female and male agro-dealers. Nearly 40% of the interviewed agro-dealers were members of the Uganda National Agro-input and Dealers' Association (UNADA), which is an umbrella association agro-dealers in the country. The association was formed in 2003, and it aims to promote exchange of ideas and skills, and enforce a code of fair business conduct among its members in order to provide improved services to farmers and contribute to the modernization of the country's agricultural sector (UNADA, 2004; Wandulu, 2004).

Roughly 41% and 42% of the interviewed agro-dealers had some level of knowledge about biopesticides and IPM, respectively. This means that the low

Table 1. Agro-dealer characteristics.

Variable	Mean	SD
Age of agro-dealer (years)	32.54	9.73
Gender of agro-dealer (1 = male)	0.48	0.50
Ownership of an agro-input shop (1 = yes)	0.50	0.50
Education of agro-dealer (years)	13.10	2.54
Agro-dealership experience (years)	6.28	5.64
Membership in UNADA (1 = yes)	0.38	0.49
Registered with MAAIF (1 = yes)	0.54	0.50
Attended safe pesticide use training course (1 = yes)	0.60	0.49
Certified as an agro-dealer by MAAIF (1 = yes)	0.55	0.50
Has knowledge of biopesticides (1 = yes)	0.41	0.49
Has knowledge of IPM (1 = yes)	0.42	0.49
Has ever received training on pest diagnosis and management (1 = yes)	0.67	0.47
Has ever received training on alternatives to pesticides (1 = yes)	0.58	0.49
Has ever received training on pesticide risks (1 = yes)	0.73	0.45
No. of observations	557	

Table 2. Shop characteristics.

Variable	Mean	SD
Years in operation	7.24	6.50
Number of workers	2.27	1.56
Shop's distance to nearest competitor (km)	0.23	0.69
Shop's distance to main input supply company (100 km)	1.67	1.63
Shop's distance to Kampala (100 km)	2.19	1.51
At least one staff or affiliate is a certified agro-dealer (1 = yes)	0.82	0.38
Shop is licensed with MAAIF (1 = yes)	0.52	0.50
Shop has ever been inspected by MAAIF (1 = yes)	0.80	0.40
Sells at least one biopesticide product (1 = yes)	0.16	0.37
Sells at least one high-risk pesticide product (1 = yes)	0.98	0.14
At least one staff has suffered pesticide-related illness (1 = yes)	0.29	0.45
Shop engages in repackaging of pesticides (1 = yes)	0.10	0.30
Sells pesticides and household commodities in the same shop (1 = yes)	0.08	0.27
No. of observations	557	

level of awareness of biopesticides among smallholder farmers observed by previous studies (e.g. Constantine et al., 2020; Muriithi et al., 2021) is also applicable to agro-dealers. This also resonates with arguments that limited knowledge of and access to IPM strategies and inputs are among the major obstacles to IPM promotion in the Global South (Alwang et al., 2019; Parsa et al., 2014). Worryingly, 15% of the pesticide dealers reported to have not received any pesticide-related training. At least two-thirds of the agro-dealers claimed to have received training on pest management and pesticide risks to human health and the environment. Most of them received training on these topics when they followed the mandatory five-day course on safe handling and use of pesticides offered by MAAIF and Makerere University as part of the requirements of being a certified agro-dealer in the country (Kyamanywa et al., 2013).

Figure 2 shows the types of products stocked in the agro-inputs shops visited. While all the shops were selling pesticides, more than 85% of them also sold seeds, fertilizers and farm tools. Personal protective equipment (PPE) was sold in nearly 80% of the shops, implying that about 20% of shops had stocked pesticide products without accompanying them with the necessary safety equipment. This is troubling because using pesticides without wearing PPE items poses high health risks. The unavailability of PPE in local shops has been recognized as one of the major reasons for their limited use among smallholder farmers in Uganda (Andersson & Isgren, 2021) and other African countries (Mengistie et al., 2017; Tambo et al., 2021). Nearly 30% of agro-input shops reported that at least one staff member had experienced acute pesticide-related symptoms, such as headache, sneezing, eye irritation, skin irritation, and nausea (Table A1 in the appendix). This is not surprising, given the limited use of standard PPE items by agro-dealers when working with pesticides (Table A2 in the appendix).

When asked about the most sold product in the past year in terms of number of transactions, a large share (70%) of the interviewed agro-dealers mentioned pesticides (Figure 3). Each shop had a median estimate of 10 pesticide transactions per day. In a survey of 975 Ugandan agro-dealers about a decade ago, Lamontagne-Godwin and Taylor (2013) found that seed was the most important product stocked in shops (in terms of number of transactions), but our results and that of Staudacher et al. (2021) indicate that the most stocked and best-selling product in recent years has been pesticides. This is not surprising because the quantity of pesticides imported into Uganda has increased substantially over the past two decades; from an estimated 3,000 tonnes (valued at 13.8 million USD) in 1998 to about 19000 tonnes (valued at 82.6 million USD) in 2018 (FAOSTAT, 2022). The increased use of pesticides in Africa has been attributed to several factors, including intensified pest pressure and outbreaks of new invasive pests, lack of advice on alternative pest control methods, income and population growth, input market liberalization, farm input subsidies, and inadequate regulatory oversight (Andersson & Isgren, 2021; Snyder et al., 2018; Tambo et al., 2020; Williamson et al., 2008).

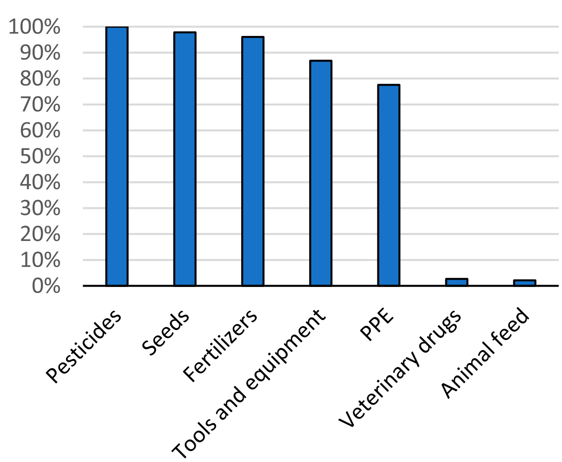

Figure 2. Types of products sold (n = 557).

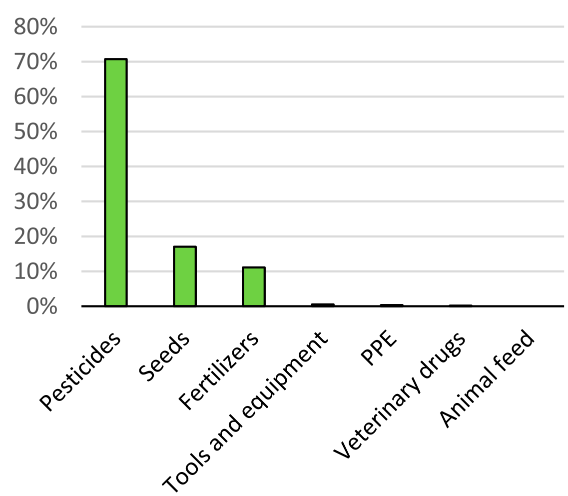

Figure 3. Most sold product in 2021 (n = 557).

3.2. Compliance with regulatory requirements

The results in Table 1 show that almost half (46%) of the agro-dealers had not registered with MAAIF, even though it is a requirement under the Uganda's Agricultural Chemicals (Control) Act, 2006 (GoU 2007). Additionally, 40% of the sample had not attended the mandatory safe use and handling of pesticides course and 45% had not been certified as an agro-dealer by MAAIF, although these are prerequisites for selling pesticides in the country. Coincidentally, Staudacher et al. (2021) also found that 44.3% out of a sample of 442 agro-dealers in Central and Western Uganda did not possess the necessary certification. Our results indicate that about 82% of the shops had at least one certified agro-dealer working in the shop. This implies that among the 250 shops where the interviewed agro-dealer did not have the mandatory certificate of competency in safe pesticide use, 40% of them had at least one affiliate (mostly the absentee owner) who was in possession of the required certificate. This lends support to arguments that some licensed and certified agro-input shop owners employ untrained shop attendants, which may affect the quality of services provided to customers (Lekei et al., 2014; Odame & Muange, 2011). Table 2 also shows that close to half of the shops did not have a trading license from MAAIF, which is a violation of one of the requirements for operating an agro-input business in Uganda (USAID et al., 2016).

Ten percent of the shops do engage in repackaging pesticides into smaller containers for sale, which is an illegal practice. Besides potential health hazards, the repackaged products are prone to counterfeiting, which remains a major challenge in the agro-inputs industry in Uganda (Andersson & Isgren, 2021; Tetra Tech, 2018). Figure 4 shows that about 2.5% of the pesticide dealers were selling veterinary products and/or animal feed, even though it is illegal for a Ugandan agro-input shop to deal in both crop and animal husbandry inputs. Moreover, 8% of the shops were dealing in pesticides and household commodities on the same premise, which is prohibited. However, this finding is encouraging, given that a 2009 census of Ugandan agro-dealers revealed that 52% engaged in repackaging of agro-inputs and 31% did not have separate premises for agro-inputs and general merchandise (ATU Ltd, 2009). Overall, our results suggest that there is inadequate enforcement of pesticide regulations, and this is consistent with the findings of previous research on the pesticide sector of Uganda (Andersson & Isgren, 2021; Staudacher et al., 2021; Tetra Tech, 2018).

3.3. Attitudes towards biopesticides and pesticide alternatives

Almost all (98%) of the agro-input shops were selling at least one HHP, which can have adverse consequences for human health and the environment (WHO, 2020). The most common HHP was dichlorvos insecticide, which was found in 81.5% of the shops (Table A3 in the appendix). On the other hand, only 16% of the shops were also selling biopesticides, which were mostly azadirachtin-based products (Neemicide and Nimbecidine). Figure 4 presents the key reasons given by the agro-dealers for not stocking biopesticides. Roughly 45% of them were not

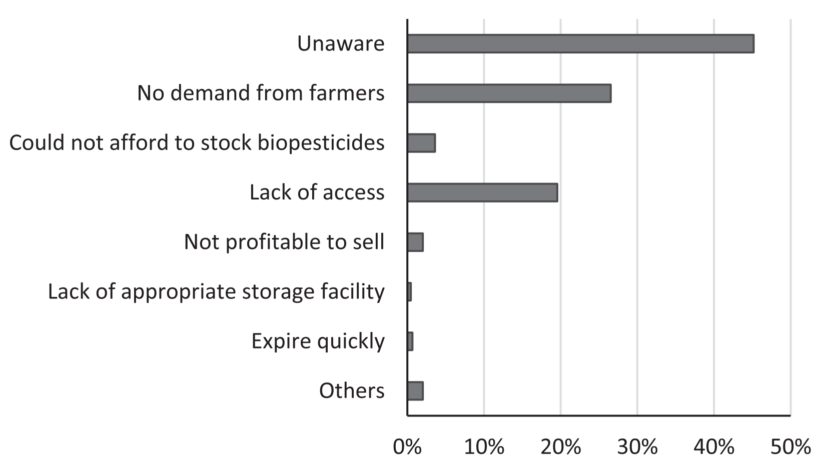

Figure 4. Main reason for not selling biopesticides (n = 445).

trading in biopesticide products because of a lack of awareness. Other important constraints mentioned include a lack of demand from farmers and a lack of access to biopesticide products. Similar challenges have been reported by a sample of agro-dealers in a neighbouring country (Kenya) (Constantine et al., 2020).

Table 3 reports agro-dealers' perceptions of biopesticides compared to synthetic pesticides, which may impede the promotion of biopesticides in the country. Not surprisingly, more than half (52%) felt that synthetic pesticides are more readily available compared to biopesticides. More than one-third of the agro-dealers were unable to compare biopesticides to synthetic pesticides in terms of affordability, effectiveness, knowledge required, speed of action and working on a wide range of pests, given the limited awareness of biopesticides. However, among the agro-dealers familiar with both categories of pesticides, the majority perceived that synthetic pesticides are more affordable, effective, work faster and can be applied on a wide range of pests than biopesticides. Conversely, over two-thirds (68%) of the agro-dealers consider biopesticides to be safer to human health and the environment than synthetic pesticides. These perceptions of biopesticides expressed by agro-dealers are consistent with those shared by smallholder farmers (Constantine et al., 2020). Our results suggest that the potential health and environmental benefits of biopesticides that agro-dealers are aware of would not be realized if other important issues such as accessibility and perception of efficacy are not tackled. Literature has shown that there is increased demand for biopesticide products if there are policy incentives to promote their usage, for example by facilitating increased availability and affordability by relocating subsidies on synthetic pesticides to biopesticides (Tambo et al., 2020).

Table 3. Perception of biopesticides compared with synthetic pesticides (n = 557).

Criterion	Better	Same	Worse	Don't know
Availability	5.75	8.80	52.24	33.21
Affordability	11.49	12.03	37.70	38.78
Effectiveness	12.03	13.64	33.39	40.93
Knowledge and skills needed	13.64	25.49	21.90	38.96
Work faster	8.26	11.13	36.09	44.52
Work on wide range of pests	11.13	13.11	29.98	45.78
Safe to human health	68.04	7.00	0.72	24.24
Safe to the environment	68.22	7.18	0.36	24.24

Table 4. Non-chemical measures recommended to farmers (n = 557).

Recommendation	Percent
Regular monitoring	62.84
Use of pest resistant or tolerant crop varieties	54.58
Cultural practices (e.g. crop rotation, intercropping)	80.97
Mechanical control (e.g. handpicking of pests)	31.96
Use of biopesticides	18.85
Encouraging natural enemies into farm	14.54
Use of pheromone traps	23.16
Use of ash or sand for pest control	23.88

The agro-dealers were asked to indicate other pest management practices they usually advise their customers to implement, besides the use of synthetic pesticides. The results in Table 4 show that about 80% of the agro-dealers reportedly recommend the adoption of cultural pest control strategies, which include crop rotation, intercropping, fertilization, trap cropping and farm sanitation. More than half of the agro-dealers also said they advise their customers to regularly monitor their fields and scouts for pests or use pest resistant crop varieties. Other alternatives to synthetic pesticides recommended by less than a third of the agro-dealers include mechanical control measures, use of biopesticides, biocontrol with predators, use of pheromone traps, and application of ash and sand.

As earlier indicated, non-chemical control methods are part of the curriculum of the certification training course for agro-dealers in Uganda, and this may have played a key role in impacting knowledge. While we are unable to confirm if most of the agro-dealers actually do give these recommendations to farmers as they claimed (given that it can affect sales of their pesticide products), at least these results suggest that some of the agro-dealers are aware of environmentally-friendly alternatives to synthetic pesticides for pest management. The use of mystery shopping (e.g. see Staudacher et al., 2021) in future studies would be useful to understand the extent to which the agro-dealers do recommend pesticide alternatives to their customers.

3.4. Determinants of agro-dealer certification

As earlier noted, holding a certificate in safe pesticide use is a mandatory requirement for agro-dealers in Uganda and elsewhere, but only 55% of the interviewed pesticide dealers had this certificate. In this section, we examine the factors influencing compliance with agro-dealer certification. When asked about the reasons for the lack of certification, nearly

20% of the non-certified agro-dealers were either not aware of the need to get certified or considered the certification cost of 250,000 UGX to be prohibitive, while about 16% of them claimed to have started the registration process, which is often delayed by the regulatory authorities due to limited resources. Travel distance to where the certification training course is held (usually in the capital Kampala) was also identified as a major obstacle to agro-dealer certification in Uganda (Table 5).

The probit regression results in Table 6 show that age of agro-dealer is significantly and positively correlated with certification, meaning that older agro-dealers are more likely to be certified. Similarly, the number of years of experience as an agro-dealer is significantly related to certification. Thus, the likelihood of being a certified agro-dealer increases with age and experience, perhaps because older and experienced agro-dealers are more likely to have had many years of opportunity to participate in the certification course. It is also likely that they have had several contacts with regulatory authorities and have been admonished to get certified. The gender variable is not statistically significant, indicating that certified agro-dealers are inclusive of both females and males.

The results also show that educated agro-dealers are significantly more likely to have the safe pesticide use certificate. More specifically, an extra year of schooling is associated with a 3.6- percentage point higher probability of being a certified agro-dealer. A plausible explanation is that educated agro-dealers see the value of being certified, or are more likely to successfully follow the training course and pass the exam. In fact, a few of the agro-dealers stated that they have not registered with regulatory agencies because they do not have the necessary education qualification (see Table 5). Shop owners are about 11 percentage points more likely than employees to be certified agro-dealers. A UNADA member has roughly a 15-percentage point higher likelihood of being a certified agro-dealer than a non-member, possibly because UNADA's code of conduct obliges members to attend the certification course on safe use and handling of pesticides (UNADA, 2004). Moreover, as highlighted earlier, many of the UNADA members reportedly benefit from training opportunities, which may include the safe pesticide use certification course.

We find that inspected agro-input shops have a 13.5-percentage point greater likelihood of having certified agro-dealers. This is likely because the quality control inspections conducted by MAAIF include checks for compliance with the necessary certification requirements. On the other hand, the results show that working in a licensed or an unlicensed shop does not significantly affect certification. Put differently, both licensed and unlicensed shops have an equal likelihood of having certified and uncertified agro-dealers.

Results in Table 6 also show that the propensity to get certified decreases with distance to the nearest competitor. This means that agro-dealers located in areas with high concentration of competitors are more likely to seek certification, possibly due to easy access to information about the certification process

Table 5. Reasons for lack of certification (n = 256).

Reasons	Percent
Cost of certification	19.53
Unaware of the need to get certified	19.14
In progress	16.40
Distance to the location of certification training	13.28
Time constraint	5.86
No perceived need	5.08
Just started the business	2.73
Covid restrictions	1.95
Do not have the academic qualification	1.56
Unaware of the process	1.56

Table 6. Determinants of agro-dealer certification.

	Coefficient	Standard error	Marginal effect
Age of agro-dealer (years)	0.015*	0.008	0.005
Gender of agro-dealer (1 = male)	−0.102	0.120	−0.033
Education of agro-dealer (years)	0.110***	0.025	0.036
Agro-dealer is shop owner (1/0)	0.345**	0.142	0.112
Agrodealership experience (years)	0.455***	0.127	0.013
UNADA membership (1/0)	0.390***	0.130	0.148
Credit access (1/0)	0.137	0.121	0.045
Works in a licensed shop (1/0)	0.016	0.042	0.005
Shop inspected by MAAIF (1/0)	0.414***	0.146	0.135
Distance to closest competitor (km)	−0.178**	0.089	−0.058
Distance to closest input supplier (100 km)	0.180***	0.062	0.059
Distance to Kampala (100 km)	−0.300***	0.069	−0.098
Constant	−2.430***	0.436	
Observations	557		
LR chi^2	128.36***		

Notes: ***, **, and * denote 1%, 5% and 10% statistical significance levels, respectively.

or a higher incentive to acquire the necessary certificate in order to increase competitiveness among peers. Agro-dealers in close proximity to the capital city (Kampala) are more likely to be certified. This is not surprising because the certification course is usually offered at Makerere University in Kampala, making it expensive for agro-dealers in remote locations to participate. This corroborates agro-dealers' claims (Table 5) and evidence from previous research (Staudacher et al., 2021) that distance to training sites is a major obstacle to agro-dealer certification. Lastly, we find that agro-dealers living farther away from input supply companies have a lower likelihood of certification. In summary, the regression results show that a Ugandan agro-dealer's decision to get certified is influenced by several socio-economic, location and institutional factors.

3.5. Effects of agro-dealer certification

The multivariate probit estimates of the relationship between certification and agro-dealer's knowledge of and practices related to biopesticides and IPM are presented in Table 7. We find that mandatory certification on safe use of pesticides is significantly and positively associated with knowledge and sale of biopesticides. The marginal effect estimates suggest that certified agro-dealers are 10 percentage points more likely than their non-certified counterparts to be aware of biopesticides and sell biopesticide products in their shops. Certification is also significantly correlated with a 9-percentage point increase in an agro-dealer's knowledge of IPM.

Table 8 reports the IPWRA and kernel matching estimates of the effects of agro-dealer certification on the three outcome variables. An overidentification test for covariate balancing shows an insignificant chi-squared value ($chi^2 = 12.3112$; $\rho = 0.5023$), confirming that the covariates are balanced and thus the propensity-score model is correctly specified (Imai & Ratkovic, 2014). Similarly, Figure A1 in the appendix demonstrates a sufficient overlap in the distribution of the propensity scores between certified and non-certified agro-dealers, suggesting a satisfaction of the overlap or common support condition. The ATET estimates from the doubly robust analysis indicate

Table 7. Determinants of agro-dealers' knowledge and sale of biopesticides.

	Knowledge of IPM		Knowledge of biopesticides		Sells biopesticide products	
	Coefficient	ME	Coefficient	ME	Coefficient	ME
Certified agro-dealer (1/0)	0.261**	0.091**	0.283**	0.101**	0.439***	0.099***
	(0.124)	(0.043)	(0.124)	(0.044)	(0.154)	(0.034)
Age of agro-dealer (years)	−0.005	−0.002	0.002	0.001	−0.001	−0.000
	(0.008)	(0.003)	(0.008)	(0.003)	(0.009)	(0.002)
Gender of agro-dealer (1 = male)	0.385***	0.134***	0.338***	0.121***	0.218	0.049
	(0.117)	(0.040)	(0.115)	(0.040)	(0.138)	(0.031)
Education of agro-dealer (years)	0.146***	0.051***	0.097***	0.035***	0.046*	0.010*
	(0.027)	(0.008)	(0.026)	(0.009)	(0.027)	(0.006)
Agro-dealer is shop owner (1/0)	0.018	0.006	0.082	0.029	0.022	0.005
	(0.136)	(0.047)	(0.135)	(0.048)	(0.159)	(0.036)
Agrodealership experience (years)	0.031**	0.011**	0.009	0.003	−0.039**	−0.009**
	(0.013)	(0.004)	(0.013)	(0.005)	(0.016)	(0.004)
UNADA membership (1/0)	0.136	0.047	0.057	0.020	0.116	0.026
	(0.126)	(0.044)	(0.123)	(0.044)	(0.138)	(0.031)
Credit access (1/0)	0.256**	0.089**	0.012	0.004	0.177	0.040
	(0.117)	(0.040)	(0.116)	(0.041)	(0.141)	(0.032)
Works in a licensed shop (1/0)	−0.029	−0.010	0.053	0.019	0.082*	0.019*
	(0.042)	(0.015)	(0.041)	(0.015)	(0.047)	(0.010)
Shop inspected by MAAIF (1/0)	0.170	0.059	−0.136	−0.049	−0.030	−0.007
	(0.141)	(0.049)	(0.140)	(0.050)	(0.176)	(0.040)
Distance to closest competitor (km)	0.021*	0.007*	0.025**	0.009**	−0.005	−0.001
	(0.012)	(0.004)	(0.010)	(0.004)	(0.010)	(0.002)
Distance to input supplier (100 km)	−0.042	−0.015	0.146**	0.052**	0.190**	0.043**
	(0.061)	(0.021)	(0.061)	(0.022)	(0.088)	(0.020)
Distance to Kampala (100 km)	0.072	0.025	−0.172***	−0.062***	−0.234**	−0.053**
	(0.067)	(0.023)	(0.067)	(0.023)	(0.102)	(0.023)
Constant	−2.486***		−1.936***		−1.952***	
	(0.444)		(0.413)		(0.500)	
Observations	557		557		557	

Notes: ***, **, and * denote 1%, 5%, and 10% statistical significance levels, respectively.
Numbers in parentheses are robust standard errors. ME = marginal effect.

Table 8. Treatment effects of agro-dealer certification.

	IPWRA estimates		Kernel matching estimates		
Outcome variable	ATET	Robust SE	ATET	SE	Γ
Knowledge of IPM (1/0)	0.102*	0.053	0.086*	0.048	1.45-1.50
Knowledge of biopesticides (1/0)	0.120**	0.054	0.111**	0.047	1.45-1.50
Sells biopesticide products (1/0)	0.084**	0.038	0.099***	0.034	1.55-1.60

Notes: ***, **, and * denote 1%, 5%, and 10% statistical significance levels, respectively. Γ= critical level of hidden bias.

that agro-certification is significantly associated with 10 and 12 percentage points increase in knowledge of IPM and biopesticides, respectively, as well as an 8-percentage point increase in the probability of the sale of biopesticides. The kernel matching results also show that certified agro-dealers are 9 and 11 percentage points respectively more likely to know IPM and biopesticides, and are 10 percentage points more likely to sell biopesticide products when compared to matched non-certified agro-dealers.

The critical gamma level (Γ) values in the last column of Table 8 indicate that the estimated treatment effects of agro-dealer certification are not sensitive to hidden bias. For instance, the Γ values of 1.45-1.50 signify that the significant effects of certification on agro-dealers' knowledge of IPM and biopesticides would be questionable only if an unobserved covariate caused the certified and non-certified agro-dealers to differ in their odds of participating in the certification scheme by a factor of about 1.50. Overall, the regression results presented in Tables 7 and 8 suggest that enforcing compliance with agro-dealer certification requirements has the potential to raise awareness of sustainable pest management practices and stimulate the sale of biopesticide products.

The results are also in line with previous studies that found a significant relationship between agro-dealer training and pesticide knowledge and safe pesticide practices, including a reduction in the sales of unregistered pesticides (Staudacher et al., 2021; Vaidya et al., 2017). Our results are also comparable to studies on the environmental benefits of certification schemes (Asfaw et al., 2010; Blackman & Naranjo, 2012; Ibanez & Blackman, 2016; Sellare et al., 2020). Although not related to agro-dealers, these previous studies have shown that the participation of farmers in sustainability certification schemes (such as Fairtrade, GlobalGAP and Organic) significantly increases the use of environmentally-friendly production practices, and reduces chemical input use and the incidence of acute pesticide poisoning.

Table 8 also shows the results for the other determinants of agro-dealers' knowledge and sale of biopesticides. We see that besides certification, only the education variable exerts a significant effect on all the three outcome variables. Specifically, an agro-dealer's knowledge of IPM and biopesticides as well as the decision to sell biopesticide products increase significantly with education. This is plausibly because education enhances access to agricultural information and the ability to decipher the information more effectively (Foster & Rosenzweig, 2010). We also find that male agro-dealers are 33.8 and 38.5 percentage points more likely to know about biopesticides and IPM, respectively, than their female counterparts. This may be reflective of the well-known gender knowledge gap in agriculture (Quisumbing et al., 2014). Distance from input supply companies has a significant positive relationship with knowledge and sale of biopesticides. Conversely, agro-dealers located in closer proximity to Uganda's capital (Kampala) are more likely to be aware of and sell biopesticide products, perhaps due to better access to training opportunities on safer plant protection products. This is in line with Staudacher et al. (2021), who found that distance from Kampala is associated with a reduction in safe pesticide use knowledge and practices.

4. Conclusion

In this study, we have shown that agro-dealer certification can play an important role in increasing knowledge and the supply of environmentally-benign pest control products, such as biopesticides. Achieving the positive outcomes associated with agro-dealer certification will require the strengthening of pesticide regulatory systems to enforce agro-dealer compliance with certification requirements, as almost half of the agro-dealers in our sample were not certified or accredited by regulatory authorities. Aside from regulatory enforcement actions, our findings demonstrate that a decentralization of certification training courses can foster increased participation in agro-dealer certification schemes, which can have positive implications for the promotion of environmentally-friendly pest control. For instance, district and local governments, agricultural faculties of some universities and other stakeholders, such as UNADA, could be empowered to provide local-level safe pesticide use training courses to agro-dealers and monitor regulatory compliance. Encouraging membership in agro-dealer associations is another potential mechanism for raising awareness of and promoting agro-dealer certification, given that their members are less likely to violate certification requirements. The study results showed that due to a lack of awareness, access and demand from farmers, only 16% of agro-dealers were selling biopesticides, which are considered safer alternatives to synthetic pesticides. Thus, addressing low levels of awareness of biopesticides, for example, through awareness-raising campaigns, would be important in efforts to promote safer alternatives to synthetic pesticides.

Note

1. The kernel matching results are consistent with those obtained using alternative PSM algorithms, such as radius and nearest neighbour matching.

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References

Alwang, J., Norton, G., & Larochelle, C. (2019). Obstacles to widespread diffusion of IPM in developing countries: Lessons from the field. *Journal of Integrated Pest Management*, *10*(1), 10.

Anderson, J. R., & Feder, G. (2007). Agricultural extension. In R. Evenson, & P. Pingali (Eds.), *Handbook of Agricultural Economics*, Vol. 3 (pp. 2343–2378). Elsevier.

Andersson, E., & Isgren, E. (2021). Gambling in the garden: Pesticide use and risk exposure in Ugandan smallholder farming. *Journal of Rural Studies*, *82*, 76–86.

Asfaw, S., Mithöfer, D., & Waibel, H. (2010). Agrifood supply chain, private-sector standards, and farmers' health: Evidence from Kenya. *Agricultural Economics*, *41*(3-4), 251–263.

ATU Ltd. (2009). *National agro input dealer census and needs assessment*. AT Uganda Ltd.

Becker, S. O., & Caliendo, M. (2007). Sensitivity analysis for average treatment effects. *The Stata Journal*, *7*(1), 71–83.

Berni, I., Menouni, A., El, I. G., Duca, R. C., Kestemont, M. P., Godderis, L., & Jaafari, S. E. (2021). Understanding farmers' safety behavior regarding pesticide use in Morocco. *Sustainable Production and Consumption*, *25*, 471–483.

Bhandari, G., Atreya, K., Yang, X., Fan, L., & Geissen, V. (2018). Factors affecting pesticide safety behaviour: The perceptions of Nepalese farmers and retailers. *Science of the Total Environment*, *631*, 1560–1571.

Blackman, A., & Naranjo, M. A. (2012). Does eco-certification have environmental benefits? Organic coffee in Costa Rica. *Ecological Economics*, *83*, 58–66.

Caliendo, M., & Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys*, *22*(1), 31–72.

Cappellari, L., & Jenkins, S. P. (2003). Multivariate probit regression using simulated maximum likelihood. *The Stata Journal*, *3*(3), 278–294.

Clausen, A. S., Jørs, E., Atuhaire, A., & Thomsen, J. F. (2017). Effect of integrated pest management training on Ugandan small-scale farmers. *Environmental Health Insights*, *11*, 1–10.

Constantine, K. L., Kansiime, M. K., Mugambi, I., Nunda, W., Chacha, D., Rware, H., Makale, F., Mulema, J., Lamontagne-Godwin, J., Williams, F., & Edgington, S. (2020). Why don't smallholder farmers in Kenya use more biopesticides? *Pest Management Science*, *76*(11), 3615–3625.

Deguine, J. P., Aubertot, J. N., Flor, R. J., Lescourret, F., Wyckhuys, K. A., & Ratnadass, A. (2021). Integrated pest management: Good intentions, hard realities. *A review. Agronomy for Sustainable Development*, *41*(3), 1–35.

Diemer, N., Staudacher, P., Atuhaire, A., Fuhrimann, S., & Inauen, J. (2020). Smallholder farmers' information behavior differs for organic versus conventional pest management strategies: A qualitative study in Uganda. *Journal of Cleaner Production*, *257*, 120465.

Dunn, L., Latty, T., Van Ogtrop, F. F., & Tan, D. K. (2023). Cambodian rice farmers' knowledge, attitudes, and practices (KAPs) regarding insect pest management and pesticide use. *International Journal of Agricultural Sustainability*, *21*(1), 2178804.

FAOSTAT. (2022). *Pesticides Trade*. Food and Agriculture Organization.

Foster, A. D., & Rosenzweig, M. R. (2010). Microeconomics of technology adoption. *Annual Review of Economics*, *2*(1), 395–424.

Fuhrimann, S., Van den Brenk, I., Atuhaire, A., Mubeezi, R., Staudacher, P., Huss, A., & Kromhout, H. (2022). Recent pesticide exposure affects sleep: A cross-sectional study among smallholder farmers in Uganda. *Environment International*, *158*, 106878.

Goeb, J., & Lupi, F. (2021). Showing pesticides' true colors: The effects of a farmer-to-farmer training program on pesticide knowledge. *Journal of Environmental Management*, *279*, 111821.

Greene, W. H. (2012). *Econometric Analysis, 7th Edition*. Prentice Hall.

Haggblade, S., Diarra, A., Jiang, W., Assima, A., Keita, N., Traore, A., & Traore, M. (2021). Fraudulent pesticides in West Africa: A quality assessment of glyphosate products in Mali. *International Journal of Pest Management*, *67*(1), 32–45.

Haj-Younes, J., Huici, O., & Jørs, E. (2015). Sale, storage and use of legal, illegal and obsolete pesticides in Bolivia. *Cogent Food & Agriculture*, *1*(1), 1008860.

Holmes, K., & Ogunmodede, A. (2023). *Analysis of existing regulatory framework and certification schemes for agro-input dealers: Cross country report*. Wallingford: CABI.

Ibanez, M., & Blackman, A. (2016). Is eco-certification a win–win for developing country agriculture? Organic coffee certification in Colombia. *World Development*, *82*, 14–27.

Imai, K., & Ratkovic, M. (2014). Covariate balancing propensity score. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, *76*(1), 243–263.

Imbens, G. W., & Wooldridge, J. M. (2009). Recent developments in the econometrics of program evaluation. *Journal of Economic Literature*, *47*(1), 5–86.

Kim, K. H., Kabir, E., & Jahan, S. A. (2017). Exposure to pesticides and the associated human health effects. *Science of the Total Environment*, *575*, 525–535.

Kwakye, M. O., Mengistie, B., Ofosu-Anim, J., Nuer, A. T. K., Brink, V. d., & J, P. (2019). Pesticide registration, distribution and use practices in Ghana. *Environment, Development and Sustainability*, *21*(6), 2667–2691.

Kyamanywa, S., Otim, M., Okori, P., & Jeninah, K. (2013). *Manual for pesticide dealers and applicators on safe handling and application of pesticides*. Makerere University.

Lamontagne-Godwin, J., & Taylor, P. (2013). Uganda Agrochemical dealers' practises and interactions with farmers. *World Agriculture* #1320.

Lekei, E. E., Ngowi, A. V., & London, L. (2014). Pesticide retailers' knowledge and handling practices in selected towns of Tanzania. *Environmental Health*, *13*(1), 1–9.

MAAIF. (2016). *National Agricultural Extension Strategy 2016/17–2020/21*. Ministry of Agriculture, Animal Industry and Fisheries (MAAIF).

Mabaya, E., Mugoya, M., Mubangizi, E., & Ibyisintabyo, C. (2018). Uganda Brief 2018-The African Seed Access Index.

Mengistie, B. T., Mol, A. P., & Oosterveer, P. (2017). Pesticide use practices among smallholder vegetable farmers in Ethiopian Central Rift Valley. *Environment, Development and Sustainability*, *19*(1), 301–324.

Mengistie, B. T., Mol, A. P., Oosterveer, P., & Simane, B. (2015). Information, motivation and resources: The missing elements in agricultural pesticide policy implementation in Ethiopia. *International Journal of Agricultural Sustainability*, *13*(3), 240–256.

Muriithi, B. W., Gathogo, N., Rwomushana, I., Diiro, G., Mohamed Faris, S., Khamis, F., Tanga, C., & Ekesi, S. (2021). Farmers' knowledge and perceptions on fruit flies and willingness to pay for a fruit fly integrated pest management strategy in Gamo Gofa zone. *Ethiopia. International Journal of Agricultural Sustainability*, *19*(2), 199–212.

Odame, H., & Muange, E. (2011). Can Agro-dealers Deliver the Green Revolution in Kenya? *IDS Bulletin*, *42*(4), 78–89.

Okonya, J. S., & Kroschel, J. (2015). A cross-sectional study of pesticide use and knowledge of smallholder potato farmers in Uganda. *BioMed Research International*, Article ID 759049.

Parsa, S., Morse, S., Bonifacio, A., Chancellor, T. C., Condori, B., Crespo-Pérez, V., Hobbs, S. L., Kroschel, J., Ba, M. N., Rebaudo, F., & Sherwood, S. G. (2014). Obstacles to integrated pest management adoption in developing countries. *Proceedings of the National Academy of Sciences*, *111*(10), 3889–3894.

Piñero, J. C., Paul, K., Byers, P., Schutter, J., Becker, A., Kelly, D., & Downing, D. (2018). Building IPM Capacity in Missouri Through Train-the-Trainer Workshops and Effective Partnerships. *Journal of Integrated Pest Management*, *9*(1), 24.

Popp, J., Pető, K., & Nagy, J. (2013). Pesticide productivity and food security. *A review. Agronomy for Sustainable Development*, *33*, 243–255.

Prokopy, R., & Kogan, M. (2009). Integrated pest management. In V. H. Resh & R. T. Cardé (Eds.), *Encyclopedia of Insects (second edition)* (pp. 523–528). Academic Press.

Quisumbing, A. R., Meinzen-Dick, R., Raney, T. L., Croppenstedt, A., Behrman, J. A., & Peterman, A. (eds.). (2014). *Gender in Agriculture: Closing the Knowledge Gap*. FAO and Springer.

Rani, L., Thapa, K., Kanojia, N., Sharma, N., Singh, S., Grewal, A. S., Srivastav, A. L., & Kaushal, J. (2021). An extensive review on the consequences of chemical pesticides on human health and environment. *Journal of Cleaner Production*, *283*, 124657.

Schreinemachers, P., Afari-Sefa, V., Heng, C. H., Dung, P. T. M., Praneetvatakul, S., & Srinivasan, R. (2015). Safe and sustainable crop protection in Southeast Asia: Status, challenges and policy options. *Environmental Science & Policy*, *54*, 357–366.

Sellare, J., Meemken, E. M., & Qaim, M. (2020). Fairtrade, agrochemical input use, and effects on human health and the environment. *Ecological Economics*, *176*, 106718.

Sheahan, M., Barrett, C. B., & Goldvale, C. (2017). Human health and pesticide use in sub-Saharan Africa. *Agricultural Economics*, *48*(S1), 27–41.

Snyder, J., Smart, J., Goeb, J., & Tschirley, D. (2018). *Pesticide use in Sub-Saharan Africa: Estimates, projections, and implications in the context of food system transformation*. Paper presented at the 2018 Agricultural & Applied Economics Association Annual Meeting, Washington, D.C., August 5-7.

Sones, K. R., Oduor, G. I., Watiti, J. W., & Romney, D. (2015). Communicating with smallholder farming families-a review with a focus on agro-dealers and youth as intermediaries in sub-Saharan Africa. *CAB Reviews*, *10*(30), 1–6. https://doi.org/10.1079/PAVSNNR201510030

Staudacher, P., Brugger, C., Winkler, M. S., Stamm, C., Farnham, A., Mubeezi, R., Eggen, R. I., & Günther, I. (2021). What agro-input dealers know, sell and say to smallholder farmers about pesticides: A mystery shopping and KAP analysis in Uganda. *Environmental Health*, *20*(1), 1–19. https://doi.org/10.1186/s12940-021-00775-2

Tabe-Ojong, M. P. J., Nyam, Y. S., Lokossou, J. C., & Gebrekidan, B. H. (2023). Farmer advisory systems and pesticide use in legume-based systems in West Africa. *Science of The Total Environment*, *867*, 161282. https://doi.org/10.1016/j.scitotenv.2022.161282

Tambo, J. A., Kansiime, M. K., Mugambi, I., Rwomushana, I., Kenis, M., Day, R. K., & Lamontagne-Godwin, J. (2020). Understanding smallholders' responses to fall armyworm (Spodoptera frugiperda) invasion: Evidence from five African countries. *Science of the Total Environment*, *740*, 140015. https://doi.org/10.1016/j.scitotenv.2020.140015

Tambo, J. A., Mugambi, I., Onyango, D. O., Uzayisenga, B., & Romney, D. (2023). Using mass media campaigns to change pesticide use behaviour among smallholder farmers in East Africa. *Journal of Rural Studies*, *99*, 79–91. https://doi.org/10.1016/j.jrurstud.2023.03.001

Tambo, J. A., Romney, D., Mugambi, I., Mbugua, F., Bundi, M., Uzayisenga, B., Matimelo, M., & Ndhlovu, M. (2021). Can plant clinics enhance judicious use of pesticides? Evidence from Rwanda and Zambia. *Food Policy*, *101*, 102073. https://doi.org/10.1016/j.foodpol.2021.102073

Tetra Tech. (2018). Feed the Future Uganda Agricultural Inputs Activity: Final report (November 2012-November 2017). A Report Prepared for the United States Agency for International Development (USAID).

UNADA. (2004). *Agro-Dealer code of conduct*. Uganda National Agro-input and Dealers' Association (UNADA).

USAID, URSB, URA, MAAIF MoA, & MoLG. (2016). *The regulatory compliance handbook for agro inputs businesses in Uganda: What every agro-dealer needs to know*. USAID Feed the Future Agricultural Inputs Activity.

Vaidya, A., Gyenwali, D., Tiwari, S., Pande, B. R., & Jørs, E. (2017). Changes in perceptions and practices of farmers and pesticide retailers on safer pesticide use and alternatives: Impacts of a community intervention in Chitwan, Nepal. *Environmental Health Insights*, *11*, 1–12. https://doi.org/10.1177/1178630217719270

Wandulu, J. A. (2004). Facilitating agricultural input distribution in Uganda—Experiences based on activities conducted by AT Uganda Ltd. *Uganda Journal of Agricultural Sciences*, *9*(1), 758–765.

WHO. (2020). *The WHO recommended classification of pesticides by hazard and guidelines to classification, 2019 edition*. World Health Organization.

Wiedemann, R., Stamm, C., & Staudacher, P. (2022). Participatory knowledge integration to promote safe pesticide use in Uganda. *Environmental Science & Policy*, *128*, 154–164. https://doi.org/10.1016/j.envsci.2021.11.012

Williamson, S., Ball, A., & Pretty, J. (2008). Trends in pesticide use and drivers for safer pest management in four African countries. *Crop Protection*, *27*(10), 1327–1334. https://doi.org/10.1016/j.cropro.2008.04.006

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press: Cambridge, MA.

Appendix

Table A1. Pesticide illness suffered by agro-dealers (n = 557).

Symptom	Percent
Headache	14.18
Sneezing	15.44
Nausea/vomiting	7.54
Stomach cramps	4.85
Fatigue /tiredness	3.05
Skin rash/irritation	9.69
Dizziness /feeling faint	4.49
Blurred vision	1.26
Diarrhoea	0.72
Eye irritation	8.80
Excessive sweating	1.62
Coughing	0.90

Table A2. Use of PPE items (n = 557).

PPE item	Percent
Goggles	20.29
Mask	72.89
Gloves	56.01
Coverall	40.57
Rubber boots	31.42
Cap/Helmet	10.41

Table A3. Examples of high-risk products identified in the surveyed shops (n = 557).

Pesticide products	Percent	WHO toxicity class[a]
Dichlorvos (e.g. Lava, Fumex, Vapo, Boom Super, DDforce)	81.51	Ib
Zeta-cypermethrin (e.g. Fury)	33.57	II[b]
Carbofuran (e.g. Agro-furan, Safuran, Furon, Wormforce)	32.50	Ib
Zinc phosphide (e.g. Push Out, Messe Phos)	29.08	Ib
Abamectin (e.g. Amdocs, Mectin, Flazon, Punch, Sta, Solvigo)	18.85	Ib
Beta-cyfluthrin (e.g. Thunder)	6.46	Ib
Endosulfan (e.g. Thiodan, Thionex)	5.39	II[b]
Paraquat (e.g. Gramoxone)	1.97	II[b]

Note: Examples of the trade names of the pesticide products are in brackets.

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

[b]Although classified as moderately hazardous by WHO, these pesticide products are restricted by international agreements, such as the Rotterdam and Stockholm Conventions, and are banned in Uganda.

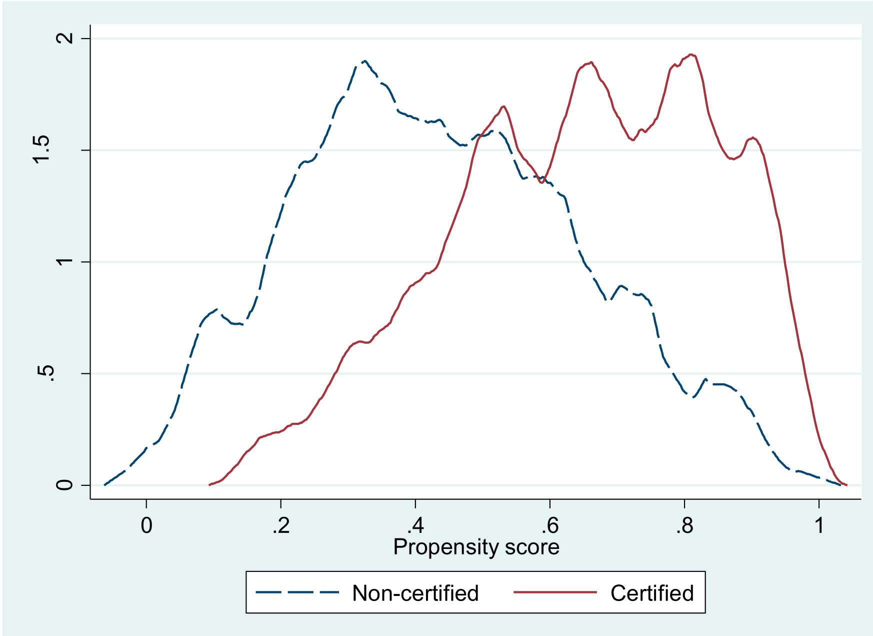

Figure A1. Kernel density of propensity scores for certified and non-certified agro-dealers.