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RESEARCH

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Investigating the feasibility of developing a collective action for biological control of fall armyworm among smallholder farmers in rural communities of Zambia

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Abstract

Background Fall armyworm, *Spodoptera frugiperda*, an alien invasive pest from the Americas, was detected in Zambia late 2016 and since has caused significant losses on maize threatening livelihood and food security. Individually, farmers continue to rely on synthetic pesticides, a reactive measure to manage new invasive insect pests, posing risks to human health, the environment and biodiversity. Biological control has been proven to be an efficient, cost effective and safe method for pest and disease management, and when adopted collectively, its effectiveness can increase. In addition, collective action has been acknowledged to be a critical component for invasive species management, but is still poorly studied in low- and middle-income countries (LMIC) where the national plant health system, in-place to prevent and manage biological invasions, is limited.

Methods To study the feasibility of creating a collective action to promote biological control for fall armyworm among smallholder farmers in rural Zambia and the social and institutional conditions needed for it to be successful and sustainable, we conducted focus group discussions and in-depth interviews in two districts with maize smallholder farmers. Our model to assess the results applies both Ostrom's 8 Design Principles for a community-based management of common-pool resources and criteria of an agricultural innovation that meet the community's requirements, and also pays attention to the exchange and brokering processes needed to match the two.

Results Our results showed that some conditions are already in place to support a collective action to manage fall armyworm such as matching rules to local conditions, collective-choice arrangement, conflict-resolution mechanism and minimal recognition of rights to organize which are supported by traditional leadership of the communities. However other conditions would need to be strengthened for the collective pest management to be sustainable. The most important criteria for a pest management innovation selected by participants from both districts, in no specific order, were price, efficacy, recommended by agrodealer/extension officer and immediate action.

Conclusions This study fills a gap in understanding social and institutional conditions in LMIC needed to sustain a collective action that aim at controlling a highly mobile and invasive pest. Our study emphasizes the need to redefine technologies and dissemination in terms of supporting the processes of co-designing innovation based on social and ecological conditions.

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Keywords Biological control, Collective action, Dilemma, Fall armyworm, Invasive species, Ostrom, Social capital, Social structure, Zambia

Background

Globalization, international trade and environmental changes significantly facilitate biological invasions, processes by which an organism is introduced and established beyond its native range, resulting in major economic, environmental and social impacts (Early et al. 2016; Paini et al. 2016; Pratt et al. 2017). Invasive alien species (non-native species, weeds, plant diseases and plant pests, causing economic or environmental harm) have disproportionate impacts on smallholder farmers in low and middle-income countries (LMIC), especially in Sub-Saharan Africa, where national capacity to prevent and manage biological invasions is limited (Early et al. 2016). The total annual cost of alien invasive species to agriculture in Africa was estimated in a recent study at USD 3.66 trillion (Eschen et al. 2021). Fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae), a highly mobile and migratory insect first detected in 2016 in West and Central Africa (Goergen et al. 2016), is estimated to cause US$9.4 billion loss in Africa (Eschen et al. 2021) and US$159 million on maize crop in Zambia specifically (Rwomushana et al. 2018). This insect pest is a successful invasive species due to its high reproduction rate, ability to feed and survive on more than 300 host plants, and its migration patterns (Day et al. 2017). Indeed, females can lay up to 1000 eggs and disperse about 500 km before oviposition. Moreover, as climatic conditions are favorable throughout the year across the African continent, there is constant food source availability and no observed diapause behavior making FAW even more difficult to control (Du Plessis et al. 2020). So far, extension and advisory services to control FAW have been directed at individuals and field level management (FAO and CABI 2019).

Invasive species can raise public-bad (a bad that is non-excludable and non-depletable, negatively affecting everyone equally) dilemmas due to their rapid spreading abilities which allow them to cross property boundaries creating interdependency among land owners (Graham et al. 2019). Consequently, if a land owner does not participate in controlling the invasive species, his/her land can become a propagule or breeding source that reinvade neighbouring fields increasing costs and effort for others (Epanchin-Niell et al. 2010; Kruger 2016). FAW dispersal mechanisms create interdependency between farmers during outbreaks. Sustainable, long-term management in a fragmented or mosaic landscape is not possible by individuals acting alone. Indeed, management of FAW is currently accomplished by individual farmers who heavily rely on the use of synthetic pesticides despite the health and environmental risks (Day et al. 2017). FAW was detected late 2016 in Zambia and in a household's survey in 2017, 60% of farmers mentioned using synthetic pesticides to control FAW as their main control method (Day et al. 2017). It was also found that a highly hazardous pesticide listed in the Rotterdam Convention was used by about 9% of famers in 2018 (Rwomushana et al. 2018). Farmers in various countries also tried controlling the pest using different cultural, mechanical, botanical and biocontrol methods with diverse outcomes (Kansiime et al. 2019; Tambo et al. 2019; Abro et al. 2021), however, the use of synthetic pesticides was always found the most common control method.

Over the last decade, collective action, defined as a process where a group of people voluntarily commit to achieve a common goal (Meinzen-Dick et al, 2004), has been identified as a key component, however not the only one, for the successful control of invasive alien species (Epanchin-Niell et al. 2010; Stallman and James 2015; Marshall et al. 2016; Graham et al. 2019; Garcia-Figuera et al. 2021). The lack of effective collective action among farmers is often a greater obstacle in controlling invasive species than lack of information (Parsa et al. 2014; Marshall et al. 2016). Many successful examples of collective pest management exist in the literature. The cotton bollworm, *Helicoverpa armigera* (Hubner), is a good example as its rapid pesticide resistance development now to 55 active ingredients (Yang et al. 2013; Dilbar Hussain et al. 2015) has stimulated a landscape approach combining both technical and organization aspects (Wilson et al. 2018). A collective strategy to manage *H. armigera*'s pesticide resistance and outbreaks with cotton and non-cotton growers in Australia was essential. Many actors were involved in this strategy, however the cooperation among farmers was crucial to successfully halt the outbreaks and the pesticide resistance development which needed a shift from a field-to-field approach to a collective and coordinated management (Wilson et al. 2018). In Colombia, transboundary leaf-cutting ants management was investigated using a participatory landscape-level research with the community (Ravnborg et al. 2000). This research focused on testing with farmers and finding the best technical and organizational solutions to a collective problem. Significant progress on ant control happened once mechanisms to encourage the majority of farmers in the area to participate in the simultaneous control of the nests. Initiatives for FAW collective action include the FAO-led Global Action for Fall Armyworm Control that has been instrumental in coordinating collaboration at regional and national levels in Africa. The actions taken involving multi-institutions and multidisciplinary teams are focusing on mass awareness campaigns, workshops for technical teams and supply of safe pesticides. Furthermore, international organizations and NGOs have provided support for specific components such as farmers awareness, research and early warning systems on a regional and national scale.

Conditions for effective collective management of invasive species have been reviewed by Graham et al. (2019) in relation to Ostrom's 8 Design Principles (1990) for a community-based management of common-pool resources and 10 factors affecting self-organized collective action (Ostrom 2009). Well-defined boundaries, monitoring and graduated sanctions alongside number of users, norms (social capital) and knowledge of the socio-ecological system were the most commonly mentioned design principles and factors respectively found in literature by Graham et al. (2019). Top-down approaches from governments, NGOs and scientists, are insufficient to ensure monitoring and management efforts across all actors due to the high transaction costs (e.g., time, labor, financial resources) (Garcia-Figuera et al. 2021). A community-based collective action building on existing institutional arrangements could therefore offer an alternative (Marshall et al. 2016). Additionally, further empirical data are needed to understand under which conditions farmers are willing to collectively manage invasive species in LMIC and which pest management options are practical and acceptable under local socioeconomic and cultural contexts.

Biological control (either classical, augmentative or by conservation), later referred as biocontrol, is the use of living organisms to suppress or impact a specific pest population (Eilenberg et al. 2001). Biocontrol can improve and protect public goods such as food security, human health, biodiversity, and ecosystem services (Delaquis et al. 2018; Burra et al. 2021). Biocontrol has been proven an effective, safe and economic solution to pest management where chemicals have failed to control pests (Menzler-Hokkanen 2006). As reviewed by Desneux et al. (2007), pesticides not only have lethal effect on pollinators and natural enemies, but also sublethal effects including development rates, malformations, perturbations of the foraging patterns and feeding behaviors. Over 30 species of indigenous parasitoids in 17 African countries have been found attacking FAW, promising potential for the biocontrol of FAW with native natural enemies (reviewed in Kenis et al. 2022). If communities decide to adopt biocontrol as an innovation to manage an invasive species, further collective action dilemmas may arise. For instance, the lack of sanctions, leadership, or monitoring system in a farming community may compromise the long-term benefits and sustainability of such initiatives if farmers fear that some won't follow the rules collectively agreed upon. Ideally, when implementing biocontrol schemes at landscape level, for example augmentative releases, all farmers would be required to decrease use of toxic products and numbers of applications in order to increase the effectiveness of the biocontrol agents (Babendreier et al. 2019). In the case of conservation biocontrol, the impact may only be seen years after consistent effort to modify and restore habitats of local natural enemies (Eilenberg 2006). This time-lag may discourage end-users, despite the fact that natural pest control can provide long-lasting economic and environmental benefits.

The objective of this study is to determine the feasibility of a collective action using biocontrol to manage FAW among smallholder farmers in rural Zambia, and the social and institutional conditions needed to successfully sustain the collective action. The authors did not intend to study current control methods used by smallholder farmers to control FAW. The following research questions were addressed: How is the farming community in rural Zambia structured in terms of social capital, leadership, information sharing, internal and external communication and trust relationships, and how does it shape a potential collective pest management? What are farmers' attitudes towards a biocontrol management option of FAW based on collective action, and what criteria of an innovation is required for adoption? Our assumption is that communities with a strong social capital, leadership and internal and external communication will be able to develop and sustain a collective action for pest management. This study is part of a transdisciplinary research project aiming at understanding how best to collectively develop and implement biocontrol programmes with smallholder farmers to control transboundary insect pests (Durocher-Granger et al. 2021).

Conceptual framework

Ostrom (1990) proposed 8 Design Principles (DPs) for a community-based management of common-pool resources. These design principles are meant to provide guidance on important components or conditions that help to successfully sustain common-pool resource management by a group of users over time and generations, but are not exhaustive. Although Ostrom' 8 Design Principles were not designed for collective pest management,

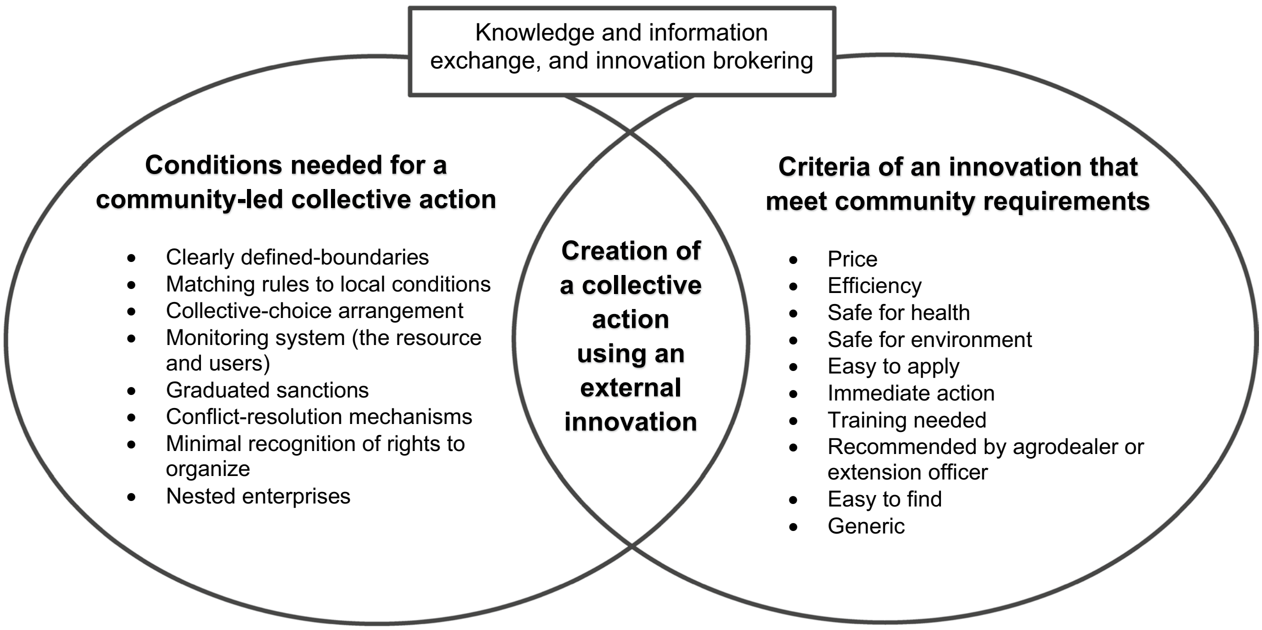

Fig. 1 Framework to study the conditions needed for the feasibility of a community-led collective action. The framework applies Ostrom's 8 Design Principles (1990) for a community-based management of common-pool resources supplemented with the criteria required by communities for an agricultural innovation to be adopted. A component related to innovation brokering and knowledge and information exchange was added to ensure a good match between externally introduced innovation and conducive conditions for collective action (Klerkx et al. 2009)

it has been found that they are well suited for addressing collective efforts and social dilemmas in agricultural ecosystems (Stallman 2011; Kruger 2016; Tafesse et al. 2020; Damtew et al. 2021; Galarza-Villamar et al. 2021). As suggested by Ostrom in 1990, further theoretical and empirical work is still needed, mainly in LMIC. Our model applies Ostrom's 8 Design Principles to the context of managing FAW, a highly mobile pest which characterizes the public bad and the sustainable and long-term management using biocontrol represents the common good to achieve by means of collective and coordinated actions. Landscape and management are highly fragmented in Zambia with around 95% of the 1.6 million small scale farmers owning less than 5 ha of land (CIAT; World Bank 2017). The successful invasive behavior of FAW allows it to quickly spread over large areas of maize fields, generating a collective action dilemma that is at the core of this study. Because biocontrol is an external innovation that needs to be introduced to the communities, we supplemented the model with the criteria required by communities for an agricultural innovation to be adopted. We have also included a component related to innovation brokering and knowledge and information exchange to indicate that there is a need for processes that ensure a good match between externally introduced innovation and conducive conditions for collective action (Klerkx et al. 2009) (Fig. 1).

Methods

Study area

The study was conducted in Zambia between December 2019 and February 2020. Four farming communities from two districts were selected: Chintembe and Chimoto (Mumbwa district, Central province, 15° 02′ S, 27° 06′ E,) and Hambale and Musika (Siavonga district, Southern province, 16° 23′ S, 28° 42′ E). Mumbwa district has an annual average precipitation between 800 and 1000 mm and annual mean temperatures are about 22.1 °C (agroecological zone IIa) (Makondo et al. 2014). Chintembe and Chimoto are located along the M20 road 11 km South from Mumbwa town. Hambale and Musika are located about 25 km North from Siavonga and 180 km South from Lusaka. Siavonga district has an annual average precipitation of < 800 mm and annual average temperature of about 26.7 °C (agroecological zone I) (Makondo et al. 2014). Maize occupies about 84% and 72% of the total area cultivated in Southern and Central provinces, respectively (Jain 2007).

Study design

To understand collective action dilemmas and local institutions, we organized focus group discussions (FDGs) (Additional file 1) in each village engaging farmers with activities on past, current and potential collective community activities and trust. With this methodology, we are seeking the explicit use of group interaction and negotiations of different perspectives to generate data allowing a better understanding of the community structure and activities (Acocella 2012; Hennink 2013). Furthermore, focus groups were used as an exploratory tool to gain insights on sensitive subjects such as trust and power dynamics among the participants and with outsiders. Relying on a collective dimension and the interactions among the participants, the role of the researcher is limited to moderator, therefore decreasing the risk of collecting biased data. Additionally, this method is useful in capturing a comprehensive range of opinions and experiences about a given topic (Hennink 2013). We hosted three FGDs for each village dividing the men, women and youth (less than 35 years old). Homogeneity among participants helped create a safe and comfortable environment to discuss openly and prevent inhibition. Whereas in heterogeneous groups, marginalized people such as women and youth may not express their views or answer questions in the presence of participants of different hierarchical positions such as men or elderly people (Acocella 2012; Sieber et al. 2014). Thus, to allow effective participation and interaction amongst all participants and to collect unbiased data from all groups, we hosted the separate FGDs.

The in-depth interviews (Additional file 2) with the community members were developed in order to collect complementary information from individual farmers, to validate focus group discussion data, and to understand further the socioeconomic context which contains sensitive information that cannot be shared during FGDs. The questionnaire was designed as semi-structured focusing on basic information about the interviewee, farmer sources of information, FAW ecological knowledge and lifecycle. Each interviewee was asked to rate from 1 (not important) to 5 (very important) the importance of each criterion of an innovation/product when choosing between pest management options; price, efficiency (ability of achieve an end goal with the limited amount of resources), safe for health, safe for environment, easy to apply, immediate action, training needed, recommended by agrodealer or extension officer, easy to find and generic. The criteria are operationalisation of the variables presented by Meijer et al. (2015) from characteristics of agricultural innovation (benefit and costs) and communication and extension to provide attributes to an innovation in term of pest management (Parsa et al. 2014).

In total, 96 farmers were involved in the FGDs and an additional 24 participants took part in the in-depth interviews as shown in Table 1. The participants were selected with the help of the camp officers and the headmen from each village and are representative of the two villages and two districts. The participants were selected based on (1) growing maize each rain season, (2) being an active member of the farming community and (3) belonging to one of the three groups (men, women and youth). Both the FGDs and interviews were tested with farmers from Chilanga district, Mapepe village, located close to the Zambia Agriculture and Research Institute (ZARI) and refined to improve the tools. Interviewers sought informed consent from the participants prior to collecting and recording their information and the data was handled in accordance with the General Data Protection Regulation (GDPR).

Data analysis

The software Atlas.ti (Version 9.1.7.0) was used to analyze the qualitative data collected through FGDs and individual interviews with a content analysis. The answers participants gave were coded and analyzed to retrieve common themes and patterns in relation to Ostrom' 8 DPs (1990). Following coding, data were split up into meaningful and relevant segments, categorized and compared and, finally, reassembled again (Boeije 2010). An inductive approach was applied: the codes were retrieved from the data, using a bottom-up approach and in vivo coding. A thematic analysis was applied to identify patterns in raw data as described by Braun and Clarke (2006). Data sharing codes or implying a common meaning were grouped and compared. This analysis was approached with a contextualist method in order to describe the experiences and meanings expressed by the participants (realist method) and to fit and contextualize them in the context of rural Zambia with the support of theories on collective action (constructive method).

From the in-depth interviews, mean (± SD) calculated from rating of each criterion of a product for selection, amount spent on pesticide and amount willing to spend on biocontrol products were analyzed using a two-sample

Table 1 Descriptive statistics of the participants involved in the focus group discussions and in-depth interviews

Region			Participants		
Focus group discussions					
Province	District	Village	Men	Women	Youth
Central	Mumbwa	Chintembe	8	8	8
		Chimoto	8	8	8
Southern	Siavonga	Hambale	8	8	8
		Musika	8	8	8
In-depth interviews					
Central	Mumbwa	Chintembe	2	2	2
		Chimoto	2	2	2
Southern	Siavonga	Hambale	2	2	2
		Musika	2	2	2

t-test assuming equal variances between Mumbwa and Siavonga districts. Stata software (Version 17.0) was used for the tests and levels of significance were tested at 1%, 5% and 10% as the basis for rejecting the null hypothesis.

Results

This section provides details on the situation at the time of the study (rain season 2019–2020) on FAW knowledge, pesticide expenses and biocontrol followed by results from the FGDs on past, current and potential collective activities, local institutions, and trust, reciprocity and reputation within the communities in relation to Ostrom's 8 DPs. This section is also supported and complemented by qualitative and quantitative data from the in-depth interviews with farmers on criteria of an innovation for adoption and knowledge and information exchange, and innovation brokering.

FAW knowledge, pesticides expenses and biocontrol

During individual interviews, farmers were asked to identify images of FAW lifecycle stages compared to common pests of maize in Zambia namely *Busseola fusca* (Fuller) (maize stalk borer), *Spodoptera exempta* (Walker) (African armyworm) and *Helicoverpa armigera* (Hübner) (cotton bollworm). Identification of the right images is captured in Table 2 per district and lifecycle category. Very few farmers identified correctly the FAW stages when compared to other common pests affecting maize in Zambia. When asked to organize the FAW lifecycle, in general, the pupa stage was not recognized or was misplaced in the cycle compared to the correct order (moth-egg-caterpillar-pupa). Follow up questions prompted the participants to explain further the FAW cycle. Eight farmers in Mumbwa mentioned that FAW comes from a butterfly that lays eggs on maize. In Siavonga, four farmers mentioned that eggs were deposited on the maize by an insect, but only one mentioned the insect was a butterfly. In Mumbwa, nine farmers explained that the larva was going into the soil or turning into a butterfly after damaging the crop. In Siavonga, four farmers explained that they either change to another stage or fly away while the others farmers could not explain where the larva went after damaging their maize.

Farmers in Mumbwa spend on average 1162 Zambian Kwachas (K) (±K2,534) annually (range K150–K10,000) on pesticide depending on the size of their field and type of crops while in Siavonga, farmers spend on average K172 (±K202) annually (range K0–K550) and half of the participants don't buy pesticides. No significant difference was found between districts on the mean amount spent on pesticides (*t*-test = 1.3503, *p*-value = 0.1907). All the 24 farmers mentioned that they would be willing to try biocontrol options and in Mumbwa would spend on average K233 (±K180) and in Siavonga K329 (±K123) for biocontrol products. No significant difference was found between both districts on the amount they were willing to pay for biocontrol products (*t*-test= -1.5211, *p*-value = 0.1424).

When asked if they had heard of biocontrol, all 12 farmers in Mumbwa said they had never heard of it while only two in Siavonga recalled an introductory meeting at the beginning of the project where biocontrol was mentioned as an option to control FAW. The two farmers described biocontrol as a practice that targets the pest without harming other beneficial insects and is friendly to human health and the environment. All 24 farmers were aware that once one of them see FAW in his/her field, everyone else has it, demonstrating knowledge on interdependency amongst farmers.

Applying Ostrom's 8 Design Principles

DP 1- Clearly defined boundaries. In this case study, the boundaries described during the study by participants were not geographical but institutional and traditional. Each village is under the authority of a headman, and each headman is part of a committee led by a chief. The villages involved in the current study consisted of around 130 households in Mumbwa district and 30–35 in Siavonga district. However, in Siavonga, households are located farther apart. Each farmer or newcomer is allocated a portion of land by the headman within the village to cultivate usually next to their fellow farmers but fields from different villages may border each other. Under their traditional community structure, the headman of each village engages and coordinates members for communal work. Participants involved in the FGDs and interviews explained that any collective work or activity is mostly organized within the village structural boundaries coordinated by the headmen but that they can showcase to other villages their experiences and success. If several

Table 2 Numbers of farmers

Life cycle	Egg		Larva		Adults		FAW cycle	
Districts	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect
Mumbwa	2	10	2	10	2	10	2	10
Siavonga	1	11	3	9	1	11	1	11

villages benefit from the same resources, such as the school, clinic or the road, then the committee of headmen will coordinate the villages' members to participate in the tasks required to benefit everyone. Every community participant of the study reported to be involved in some kind of collective work, from cleaning the streets during the rain season to molding bricks for building the school, one person per household would be called to participate in the activity.

DP 2- Matching rules to local conditions. Farmers explained having the option to join a cooperative for agricultural activities however the description demonstrated dissonance between external rules and the local conditions. Cooperatives were described by farmers as a top-down initiative, where communities don't have the authority to initiate their creation. Cooperatives were initiated outside the village either by the government or a local NGO where guidelines on the structure and coordination of the system was provided, but it was never a local initiative from the farmers in accordance with the traditional community structure. Moreover, each cooperative establishes a maximum capacity for the number of members able to join, on average between 20 and 30 members. To become members, farmers have to pay a membership, fees and shares. The amounts for each vary depending on the cooperative and location but mainly range between K50–K200. In Mumbwa, farmers from different villages often join the same cooperative based on shared aptitudes or income generation activities such as dairy farms or growing vegetables. To benefit from the Farmer Input Support Programme (FISP), a government programme that subsidizes farmers with inputs to boost maize production across the country, cooperatives need to be registered with the local government. The cooperative structure was established before the Zambian government started the FISP in 2002. Since its implementation, the government work with the established cooperatives to register farmers and distribute the subsidized inputs (Burke et al. 2012; Chiboola M., ZARI social scientist, personal communication). The incentive to become a member is now mainly to benefit from the discounted inputs and less exchanges happen between members [FDG-Men Musika: Fertiliser is cheap when you are in a cooperative; FGD-Men Chimoto: FISP would never look at you as an individual]. Few participants mentioned learning and sharing new skills and knowledge on farming practices as a reason to join the cooperative. At the time of data collection in 2019, in Mumbwa, 79% of the participants were involved in cooperatives, while in Siavonga only 2% were involved since most of the farmers had to cancel their membership due to lack of financial resources. Other reasons mentioned for not joining or leaving the cooperatives included lack of interest or time, poor leadership, no tangible benefits, poor communication, and distrust from previous experience.

DP 3- Collective-choice arrangement. Despite that no collective pest management project has occurred in the past, the participants had a strong opinion about the decision-making process to reach consensus in the village. For example, if some community members need to be selected to take part in an initial training, the headman would call a meeting and collectively they would discuss and agree on who would be the best learners able to transmit the knowledge to the rest of the community. This selection process is based on trust, reciprocity and reputation of individuals from previous experiences. Even if farmers already have experience on electing executive committee under the cooperative organizational system, any decision affecting the whole community is discussed, negotiated and agreed. Additionally, the headman was identified consistently as the key figure in the development of any project within the community and would need to be involved and updated regularly.

DP 4- Monitoring system. Farmers agreed that participation and activities need to be reinforced by the headman. The headman can even create rules and laws for the benefit of all and apply compulsory participation. Farmers insisted that they will encourage and demonstrate the benefits to reluctant and non-participating farmers to motivate them, and can even work on their behalf. As fields from farmers belonging to the same village are next to each other, they meet often in the field where they discuss and exchange information. These informal meetings based on trust and reciprocity can provide a space for monitoring the pest occurrence and members' adherence to rules. It was also mentioned that the whole village should be well informed on the progress and benefits of a project even if only a few selected farmers will take part in a training initially or be involved during a pilot phase. Local and national plant health authorities do not establish or reinforce rules with incentives or sanctions neither monitor farmers to ensure proper pest management. Indeed, poor and unpredictable telecommunication networks and road infrastructure in remote rural areas make it challenging for the national plant health authorities to regularly monitor farmers' field and enforce rules.

DP 5 - Graduated sanctions. The headman was again identified as the authority to call meetings, to ensure farmers' participation in projects, and to be involved in cases where a fellow farmer does not comply with the rules established by the group. Discussing with the farmers to explain the benefits and encouraging participation were the most common solutions proposed, however no sanctions such as fines or payments where mentioned. Two groups decided that farmers who do not participate would be removed from the working group. No sanction or incentives is implemented by plant health authorities for pest management as mentioned above.

DP 6- Conflict-resolution mechanisms. Traditional leaders such as the headman were identified by participants to organize meetings and play a mediator role when needed to resolve conflicts [FGD-Men Chimoto: We can ask the headman to ensure participation through a meeting on condition that the headman should have been informed of the training, FGD-Men Chintembe: The headman has the authority to ensure inclusiveness into the collective effort]. If conflicts can't be resolved, it will then be passed on to the senior headman before escalating to the chief. Extension officers and local governments do not play a role in conflict-resolution of farming communities (Sheleni H., extension officer, Ministry of Agriculture, personal communication).

DP 7 - Minimal recognition of rights to organize. At local and national levels, plant health authorities in Zambia provide recommendations on how best to manage FAW field-by-field but collective pest management is not known from any community member. Plant health authorities rely mainly on local extension officers to provide advisory services to farmers and distribute insecticides for the control of FAW. Despite the fact local and national governments encourage the establishment of cooperatives and provide pest management advice, traditional leaders are more trusted and respected for the establishment and enforcement of rules within the communities for a wide range of activities. Government officers can't overrule chief or headman authorities who are considered of higher hierarchy.

DP 8 - Nested enterprises. Villages are already divided in sections in a decentralized manner. Participants mentioned that each section would elect one representative who can be involved in a project or be trained on everyone's behalf. They would therefore ensure to reach out to all farmers of the village [FGD-Men Chimoto: We can have decentralized group trained to prepare [the product] for distribution to the village around the divided groups].

Rating of criteria of an innovation

During the in-depth interviews, when asked to rate from 1 (not important) to 5 (very important) for selecting pest management options, on average farmers in Mumbwa rated price as the most important criterion of a product, followed by efficacy and recommended by agrodealer/extension officer. In Siavonga, farmers rated efficacy as the most important criterion, followed by price and immediate action. Easy to find and easy to apply were rated low in both communities as less important for selection. Significant differences were found between both districts in rating price, safe for health, immediate action, training needed and easy to find (Table 3).

Knowledge and information exchange, and innovation brokering

Within the community

In Mumbwa, gardens were all located in the same area close to the stream, therefore farmers interact daily and learn how to grow vegetables from each other. In Siavonga, where the farmers are farther apart, these exchanges still happen frequently, mostly involving women who meet at least once a week at the borehole to collect water. When facing a problem, farmers will consult their neighbours to know if they are facing the same issue. The lead farmer was another trusted figure within the community for agricultural knowledge as they are selected by fellow farmers to attend training, establish demonstration plots and to transfer knowledge to others.

Employed by the government, extension officers assist farmers in improving farming practices to increase crop productivity and income (Swanson and Claar 1984). The relationship that extension officers have with farmers is personal and they have a good command of farmers' agricultural situation. Being the only regular contact reaching the community, farmers are mainly dependent on the extension officer for new agricultural knowledge and updates. Furthermore, the community places itself under the authority of the extension officer. As for the headman, farmers want the extension officer to be aware of any project they are involved in, recognizing in the presence of the extension officer a warranty of trustworthiness. The role of the extension officer focuses mainly on technology and information transfer. Whenever lead farmers are not able to advise on agricultural issues, farmers can reach the extension officer by phone and meet in the communities to provide a solution. For outsiders, the extension officer is the main technical contact point with the community concerning agriculture, who will contact the headman to agree on potential projects in the village.

Outside the community

The agrodealer is a recurrent contact outside the farming community. While in Mumbwa the participants could mention several ones, in Siavonga farmers trust only one agrodealer, which they called by name, underlying a constrained relationship. Compared to the extension officers, agrodealers don't assist farmers in the communities but have their shop in town which farmers must physically visit for advice or to buy inputs. However, this exchange

Table 3 Results of two sample *t*-test (means ± SD) rating of criteria of an innovation or a product for acceptance by participants from Mumbwa and Siavonga

Characteristics	District	n	Mean	SD	*t*-value	*p*-value
Price	Mumbwa	12	5.000	0	5.2035	< 0.0000***
	Siavonga	12	3.667	0.888		
Efficiency	Mumbwa	12	4.583	0.900	0.4098	0.6859
	Siavonga	12	4.417	1.083		
Safe for health	Mumbwa	12	4.000	0.739	2.7663	0.0113**
	Siavonga	12	2.667	1.497		
Safe for environment	Mumbwa	12	3.250	1.215	0.4771	0.6380
	Siavonga	12	3.000	1.348		
Easy to apply	Mumbwa	12	1.917	1.564	-0.4302	0.6713
	Siavonga	12	2.167	1.267		
Immediate action	Mumbwa	12	2.250	1.138	-2.4010	0.0252**
	Siavonga	12	3.417	1.240		
Training needed	Mumbwa	12	1.917	1.505	-1.8269	0.0813*
	Siavonga	12	3.083	1.621		
Recommended by agrodealer or extension officer	Mumbwa	12	4.167	1.267	1.7064	0.1020
	Siavonga	12	3.167	1.586		
Easy to find	Mumbwa	12	1.667	0.888	-2.1828	0.0400**
	Siavonga	12	2.417	0.793		
Generic	Mumbwa	12	2.583	1.165	-0.4302	0.6713
	Siavonga	12	2.833	1.642		

The variables analysed were the rating between 1 and 5 between both district (1 = not important and 5 = very important)

*<0.01, ** <0.05, ***<0.001

of information is unilateral: when consulted, the agrodealer provides solutions in terms of which inputs to use. Generally, the farmers consult the agrodealers for chemicals advice only.

Exchanges with outsiders are less frequent than with the extension officers or agrodealers in the communities and every contact is strongly mediated [FGD-Youth Chimoto: [An outsider] cannot come directly to us. He has to go to the extension officer first and he/she would go to the headman and then maybe, FGD-Men Hambale: You must come through the extension officer, FGD-Women-Hambale: If someone comes to me, I will send him to the headman and he will ask for contact details]. Nevertheless, being introduced by the extension officer and headman would not be enough for an outsider to gain the trust of the community. Strongly relying on reputation and peer-to-peer control, farmers want to know everything about the person and will ask around about the reputation of this person before accepting to work with the outsider. Farmers want to be able to track and get in contact with someone for accountability in order to be able to trust the person [FGD-Women Musika: We would need to know where your shop is, FGD- Men Chintembe: I would trust someone when I know with who he had worked in the past].

Discussion

Our case study brings to light the critical role of local traditional institutions in rural Zambia and their potential to uplift a collective action for the sustainable management of FAW and other invasive species. In relation to Ostrom's 8 Design Principles, our results indicate that matching rules to local conditions (DP2), collective-choice arrangement (DP3), conflict-resolution mechanism (DP6) and minimal recognition of rights to organize (DP7) are conditions clearly in place and conducive for the successful establishment of a collective action for the communities involved in this case study. However, other conditions such as the monitoring system (DP4) and graduated sanctions (DP5) were found weaker and will need further effort to strengthen them as they are always critical in the success of a collective action. These findings are consistent with similar studies (Kruger 2016; Graham et al. 2019; Garcia-Figuera et al. 2021) suggesting that not all design principles are as important compared to common-pool resources management and that relevance of each design principle may vary according to the cultural context of farming communities. We therefore suggest that invasive species management programmes in LMIC should recognize and build on local institutions to develop collective interventions.

A well-coordinated pest management project at community level can bring significant collective benefits in the long-term such as increased livelihood through reduced pesticide expenses and yield losses, and improved environment, human health and water quality from reduced pesticide usage (Kruger 2016). However, highly mobile pests such as FAW can bring considerable social dilemmas within a farming community where the main resource is grown in a mosaic pattern over a large area or when the geographical or institutional boundaries do not match with the boundaries of the pest. In Zambia, maize is the main staple crop cultivated over an area of 1.3 m ha (FAO stats 2022) by approximately 1.6 m smallholder farmers where 71.5% own less than 2 ha and 23.8% between 2 and 5 ha of farm land (CIAT; World Bank 2017). At the onset of the rain, farmers start planting maize in small fragmented plots neighbouring each other, making FAW's main food widely available. For government officers, field boundaries may be unclear and coordinating actions or monitoring farmers can be challenging due to the high number of farmers spread across a vast territory. The data collected in our case study clearly showed that farmers abide by their local community structure which is consistent with traditional leadership in sub-Saharan Africa and rural Zambia (Tiwari et al. 2017). The boundaries defined by participants were consistently related to the village social structure led by the headman rather than the geographical boundaries delimiting villages or farms (DP1). While this demonstrates the strong social capital (shared knowledge, understanding, norms and rules), a collective action to manage a highly mobile pest affecting a large area such as FAW will require consistent effort to overcome mismatches between institutional boundaries and agroecological/geographical boundaries. Nevertheless, the well-defined leadership through the headmen committee and the chiefdom territory can provide a foundation to establish the geographical limits of the collective action. While spraying pesticides can be done in an uncoordinated manner, at farm level, according to habitat fragmentation and land boundaries, the implementation of biocontrol practices is more effective on a regional or landscape level under coordinated actions (Cumming and Spiesman 2006; Stallman and James 2015; Babendreier et al. 2019).

Conservation biocontrol through habitat management may not be immediately effective opposed to the preference indicated by farmers: the restauration of natural enemies' populations may be seen only after a few years. In this case, some farmers may decide to opt-out of the collective action if the outcomes are not readily observable, putting pressure on the commitment of other farmers or even creating a counterproductive situation. Indeed, developing a biocontrol scheme requires an efficient governing system. Farmers must jointly adopt field management and agronomic practices, such as decreasing pesticide applications, using chemicals that are non-toxic to natural enemies, keeping natural habitats and creating refuges and corridors for natural enemies (Gurr et al., 2000; White, 2019). In the case of FAW, even if the majority of farmers cooperate and follow rules, only one field not adequately managed can be enough to serve as a breeding spot to reinvade neighbouring fields.

As discussed by Ostrom (2009), if the initial rules established are not congruent with local conditions (DP2), the sustainability of a collective action might not be achieved. Our study clearly demonstrates that a collective action would be best initiated by communities due to the traditional community structure where rules comply with local conditions and stakeholders' interests and attributes (Garcia-Figuera et al. 2021) and that national and local governments can't interfere with traditional leadership (DP7). While cooperatives have contributed benefits to many isolated farmers in Zambia to reduce poverty (Pinto 2009; Öjermark and Chabala 1994), their institutional structure doesn't acknowledge the rich social capital existing in the communities, as observed by Akwabi-Ameyaw (1997) in Zimbabwe. Cooperatives are defined as "associations of persons who have voluntarily joined together to achieve a common end" (ICA 1995). It represents a legacy of the economic progress expectations following the end of the colonial regimes (Bowman 2011). Indeed, farmers joined cooperatives according to the money available for membership and with the main interest of accessing the subsidized inputs from the FISP. As an example, merging farmers from different villages, the peer-to-peer control, monitoring of the resource and users, and knowledge exchange based on trust, reciprocity and reputation are missing. Exchange, cooperation and consensus happen within the village traditional institutions rather than between members of the same cooperative. Furthermore, not only are cooperatives external initiatives but they also have a maximum number of participants which doesn't promote equality, especially towards youth who are often unable to afford the membership fees. In the case of biocontrol and pest management in Zambia, a community-based initiative developed and implemented in accordance to local social conditions would be more effective than relying on cooperatives to implement rules and a monitoring system.

The traditional power inherited by the headman would play a central role in the development or modification and enforcement of the rules agreed by the members (DP3). Although the headman is not recognized as a source of agricultural information, any rules created and enforced by him will be respected. In the establishment of a collective action, working rules must be agreed upon by the community in order to set up a system based on mutual trust promoting the required actions. Setting up such a system increases transactional costs in terms of resources and time (Oliver and Marwell 1988). Our study demonstrated that the involvement of local leaders, such as the headman, can offset these costs (Ostrom and Ahn 2009). The collective-choice arrangements, reflecting the strong social capital of the communities in rural Zambia, is a paramount condition required to be in place for effective collaboration. Another important condition to sustain trust and reciprocity needed for a collective action is the prerequisite of a monitoring system implemented by the resource users rather than external authorities (DP4). While farmers trust each other in equally participating in a project, the peer-to-peer control is maintained through traditional authority represented by the headman. If farmers do not abide to rules commonly agreed, the headman can intervene as a mediator who also secures the conflict-resolution mechanism in the community (DP6). Furthermore, farmers value the promotion of incentives rather than sanctions to motivate other farmers to join or remain in a project using demonstrations or even working on their behalf (DP5). Besides, farmers constantly insisted on the need to receive progress updates or mentioned they always receive. Monitoring systems, graduated sanctions and conflict-resolution mechanisms are strongly intertwined and deeply rooted within the traditional leadership of the villages. These principles are of paramount importance for the effective collective management of FAW due to its high mobility and reproductive rate, characteristics which can escalate quickly into outbreaks if no control method is applied. As farmers from the same village own fields next to each other, it becomes easier to jointly monitor the resource as well as exchanging knowledge and lessons learned.

When FAW was first detected in Zambia late 2016, the government quickly acted to support farmers mainly in distributing free chemical pesticides to spray (Kansiime et al. 2019). However, due to the lack of knowledge on how best to manage this new invasive species, its impressive ability to invade, rapid establishment and lack of diapause in Africa, its management quickly became challenging. Therefore, the role of the extension officer became crucial in communicating new knowledge on the pest. Extension officers have regular contact with the communities and are seen as an important source of information in agriculture. The communities already trust the extension officers; they have a good reputation for responding to requests, and their involvement in any new project is mandatory. Indeed, the trust and reputation that extension officers have gained in the communities can considerably reduce the transaction costs needed for a collective action implemented as a top-down approach. Being in charge of various villages, extension officers can connect and coordinate different communities who don't normally have regular interaction consequently increasing the outreach and impact of the coordinated actions. Additionally, their endorsement for a product or an innovation is highly valued by farmers for acceptance. Agrodealers were also identified as a local source of knowledge and information when farmers face problems with their crops, however their role could not support a collective action within the community due to their remote location and sporadic interventions. Nevertheless, they can contribute in increasing collective knowledge and valorizing collective pest management by providing nature-based advice or alternatives to chemical pesticides that meet communities' requirements. These results highlight the need to upscale training and capacity building of extension officers and agrodealers on ecosystem services, natural pest control and biocontrol products as they are the main source of information in agriculture (Constantine et al. 2020). Within the community, the continuous exchanges between farmers are an important channel for the creation and development of local knowledge (i.e. know-how, practices, skills developed by people sharing history and experiences (Beckford and Barker 2007)) supporting a collective action, as well as trust, reciprocity and reputation.

Most farmers had never heard of biocontrol as a pest management option and heavily rely on chemical pesticides as their main control method for FAW. Farmers showed willingness to pay for biocontrol products with limited knowledge on the innovation indicating openness to try new pest management practices. The limited knowledge on FAW lifecycle and differentiation with other common pests could be a constraint for a collective action as a good command of the pest cycle and behavior is crucial for its management in relation to interdependency between farmers (Tafesse et al. 2018). A previous study in Zambia (Kansiime et al. 2019) showed that 91% of farmers could recognize FAW caterpillar and damage however the images were not compared with other pest species. The current national extension system focuses on a specific topic when a new problem arises rather than looking at the whole agroecological system. Providing further training on biocontrol and the various pests found in agroecological systems would increase collective knowledge on the different management options focusing on the system rather than a single pest where farmers could collectively decide which option suits them most.

The linear model of innovation assumes that knowledge is generated by innovators, transferred by communication workers and applied by farmers (Leeuwis 2004). However, many studies have shown that characteristics of an innovation, perceptions and attitudes of farmers, and local socioecological conditions can influence its adoption or dis-adoption (Leeuwis 2004). As Mumbwa and Siavonga are located in different agroecological zones, the social and ecological conditions are therefore different. Siavonga region receives much less rain than Mumbwa and farmers have to rely on drought-tolerant crops such as sorghum, millet and cowpeas whereas Mumbwa farmers enjoy a longer rain season and can even grow vegetables during the dry season due to streams around gardens. Consequently, both communities expressed different preferences in the criteria of an innovation or product for its selection. In Mumbwa, when deciding to buy a product, farmers consider the price as their priority compared to efficacy in Siavonga. Furthermore, Mumbwa participants gave more importance than Siavonga participants to "safe for health" and "price". However, Siavonga rated higher than Mumbwa the criteria "immediate action", "training needed" and "easy to find". The distance from the communities to the agrodealer in Siavonga (at least 25 km) and the costs in transportation may partially explain the preference for a product that is easy to find and rapidly effective. In Mumbwa, various NGOs have worked in the region promoting alternatives to pesticides and conservation agriculture where safe products for health and environment have been scored high in importance. Finally, both communities rated recommended by extension officer or agrodealer an important determinant for acceptance supporting the trust and reputation that farmers have towards them. These findings support the theory that extension needs to move away from the "one-size-fit-all" dissemination methodology and should be redefined in terms of supporting the processes of co-designing innovation based on social and ecological conditions (Leeuwis 2004; Kruger 2016).

Conclusion

This study fills a gap in understanding social and institutional conditions in LMIC needed to sustain a collective action that aim at controlling a highly mobile and invasive pest. Under the traditional leadership of sub-Saharan Africa, we found that matching rules to local conditions, collective-choice arrangement, conflict-resolution mechanism and minimal recognition of rights to organize are conducive conditions already in place for the successful development of a collective action for the management of a highly mobile and invasive pest. Our study highlighted the need to understand and build on the local institutional structures in collective pest management, especially for biocontrol schemes where the long-term benefits are more effective on a landscape level and can take time to be appreciated. If properly coordinated, biocontrol schemes implemented at the landscape level have the potential to significantly reduce the need for applying pesticides, and in this case, increase food safety and security and the livelihoods of vulnerable marginalized farmers. However, further empirical research and implementation trials are needed. Indeed, this next step can be challenging for research purposes due to the large area and extended period needed to test the innovation. To successfully achieve collective management of highly mobile and invasive pests, we therefore recommend developing a long-term plan with farmers to progressively phase out pesticides and transition towards natural pest control provided by ecosystem services where chemicals are the last resort.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43170-023-00154-6.

Additional file 1. Focus group discussion questions used to assess collective action dilemmas and local institutions in rural communities of Zambia.

Additional file 2. Survey used for in-depth interviews with farmers to assess socioeconomic context, ecological knowledge and criteria of an innovation for adoption.

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Author contributions

Conceptualization: LDG, SF, DL, CL. Methodology: LDG, SF, MKK, SKM, MMC, DL and CL. Data collection: SF, SKM, MMC. Data analysis: LDG, SF. Writing–original draft preparation: LDG, SF. Writing–review and editing: MKK, SKM, MMC, DL, CL. All authors read and approved the final version of the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Interviewers sought verbal informed consent from theparticipants prior to collecting and recording their information and the data was handled in accordance with the General Data Protection Regulation (GDPR).

Consent for publication
Not applicable

Competing interests
The authors declare that they have no competing interests.

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References
Abro Z, Kimathi E, De Groote H, Tefera T, Sevgan S, Niassy S, Kassie M. Socioeconomic and health impacts of fall armyworm in Ethiopia. PLoS ONE. 2021;16(11):e0257736. https://doi.org/10.1371/journal.pone.0257736.

Acocella I. The focus groups in social research: advantages and disadvantages. Qual Quant. 2012;46(4):1125–36. https://doi.org/10.1007/s11135-011-9600-4.

Akwabi-Ameyaw K. Producer cooperative resettlement projects in Zimbabwe: lessons from a failed agricultural development strategy. World Dev. 1997;25(3):437–56.

ATLAS.ti Scientific Software Development GmbH [ATLAS.ti 22 Windows]. 2022. Retrieved from https://atlasti.com.

Babendreier D, Wan M, Tang R, Gu R, Tambo J, Liu Z, Grossrieder M, Kansiime M, Wood A, Zhang F, Romney D. Impact assessment of biological control-based integrated pest management in rice and maize in the greater Mekong subregion. Insects. 2019;10(8):226. https://doi.org/10.3390/insects10080226.

Beckford C, Barker D. The role and value of local knowledge in jamaican agriculture: adaptation and change in small-scale farming. Geogr J. 2007;173(2):118–28. https://doi.org/10.1111/j.1475-4959.2007.00238.x.

Boeije H. Analysis in qualitative research. Los Angeles: SAGE; 2010.

Bowman A. Mass production or production by the masses? tractors, cooperatives, and the politics of rural development in post-independence Zambia. J Afr History. 2011;52(2):201–21. https://doi.org/10.1017/S0021853711000235.

Braun V, Clarke V. Using thematic analysis in psychology. Qualitative Res Psychol. 2006;3(2):77–101. https://doi.org/10.1191/1478088706qp063oa.

Burke WJ, Jayne TS, Sitko NJ. 2012. Can the FISP more effectively achieve food production and poverty reduction goals? food security research project policy synthesis No 51. Available at http://wwwaec.msu.edu/agecon/fs2/zambia/index.htm.

Burra DD, Pretty J, Neuenschwander P, Liu Z, Zhu ZR, Wyckhuys KAG. Human health outcomes of a restored ecological balance in african agro-landscapes. Sci Total Environ. 2021;775:145872. https://doi.org/10.1016/j.scitotenv.2021.145872.

CIAT; World Bank. Climate-smart agriculture in Zambia. CSA Country profiles for Africa series. Washington, D.C: International Center for Tropical Agriculture (CIAT); 2017. p. 25.

Constantine KL, Kansiime MK, Mugambi I, Nunda W, Chacha D, Rware H, Makale F, Mulema J, Lamontagne-Godwin J, Williams F, Edgington S, Day R. Why don't smallholder farmers in Kenya use more biopesticides? Pest Manag Sci. 2020;76(11):3615–25. https://doi.org/10.1002/ps.5896.

Cumming GS and BJ Spiesman. Regional problems need integrated solutions: Pest management and conservationbiology in agroecosystems. Biological conservation. 2006; 131: 533-543. https://doi.org/10.1016/j.biocon.2006.02.025.

Damtew E, Leeuwis C, Struik PC, Cecchi F, van Mierlo B, Lie R, Lemaga B, Cieslik K. Communicative interventions for collective action in the management of potato late blight: evidence from a framed field game experiment in Ethiopia. Food Secur. 2021;13(2):255–71. https://doi.org/10.1007/s12571-020-01120-0.

Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M, Colmenarez Y, Corniani N, Regan E, Godwin J, Gomez J, Moreno PG, Murphy ST, Oppong-Mensah B, Phiri N, Pratt C, Silvestri S, Witt A. Fall armyworm: impacts and implications for Africa. Outlooks on Pest Management. 2017;28(5):196–201. https://doi.org/10.1564/v28_oct_02.

Delaquis E, de Haan S, Wyckhuys KAG. On-farm diversity offsets environmental pressures in tropical agro-ecosystems: a synthetic review for cassava-based systems. Agric Ecosyst Environ. 2018;251:226–35. https://doi.org/10.1016/j.agee.2017.09.037.

Desneux N, Decourtye A, Delpuech J-M. The sublethal effects of pesticides on beneficial arthropods. Ann Rev Entomol. 2007;52:81–106. https://doi.org/10.1146/annurev.ento.52.110405.091440.

Dhesi AS. Social capital and community development. Commun Dev J. 2000;35(3):199–214. https://doi.org/10.1093/cdj/35.3.199.

Dilbar Hussain M, Saleem G, Muneer Abbas. Insecticide resistance in field populations of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). J Entomol Sci. 2015;50(2):119–28. https://doi.org/10.18474/JES14-24.1.

Durocher-Granger L, Mfune T, Musesha M, Lowry A, Reynolds K, Buddie A, Giovanni C, Offord L, Chipabika G, Dicke M, Kenis M. Factors influencing the occurrence of fall armyworm parasitoids in Zambia. J Pest Sci. 2021;94(4):1133–46. https://doi.org/10.1007/s10340-020-01320-9.

Early R, Bradley BA, Dukes JS, Lawler JJ, Olden JD, Blumenthal DM, Gonzalez P, Grosholz ED, Ibañez I, Miller LP, Sorte CJB, Tatem AJ. Global threats from invasive alien species in the twenty-first century and national response capacities. Nat Commun. 2016;7:12485. https://doi.org/10.1038/ncomms12485.

Eilenberg J, Hajek A, Lomer C. Suggestions for unifying the terminology in biological control. BioControl. 2001;46: 387–400. https://doi.org/10.1023/A:1014193329979.

Eilenberg J. Concepts and visions of biological control. In: Eilenberg J and HMT Hokkanen, editors An Ecological and Societal Approach to Biological Control. Dordrecht: Springer; 2006. p. 1–11 https://doi.org/10.1007/978-1-4020-4401-4.

Epanchin-Niell RS, Hufford MB, Aslan CE, Sexton JP, Port JD, Waring TM. Controlling invasive species in complex social landscapes. Front Ecol Environ. 2010;8(4):210–6. https://doi.org/10.1890/090029.

Eschen R, Beale T, Bonnin MJ, Constantine KL, Duah S, Finch EA, Makale F, Nunda W, Ogunmodede A, Pratt CF, Thompson E, Williams F, Witt A, Taylor B. Towards estimating the economic cost of invasive alien species to african crop and livestock production. CABI Agric Bioscience. 2021. https://doi.org/10.1186/s43170-021-00038-7.

FAO and CABI. 2019. Fall Armyworm Field Handbook: Identification and Management, First Edition. Available at https://www.plantwise.org/FullTextPDF/2019/20197200644.pdf.

FAO, License FAOSTATS. CC BY-NC-SA 3.0 IGO. Extracted from: https://www.fao.org/faostat/en/#data/QCL. Accessed 13 Jul 2022.

Galarza-Villamar JA, McCampbell M, Leeuwis C, Cecchi F. Adding emergence and spatiality to a public bad game for studying dynamics in socio-ecological systems (part I): the design of musa-game for integrative analysis of collective action in banana disease management. Sustainability. 2021;13(16):9370. https://doi.org/10.3390/su13169370.

Garcia-Figuera S, Grafton-Cardwell EE, Babcock BA, Lubell MN and N McRoberts. Institutional approaches for planthealth provision as a collective action problem. Food Security. 2021; 13, 273–290. https://doi.org/10.1007/s12571-020-01133-9.

Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PLoS ONE. 2016;11:10. https://doi.org/10.1371/journal.pone.0165632.

Graham S, Metcalf AL, Gill N, Niemiec R, Moreno C, Bach T, Ikutegbe V, Hallstrom L, Ma Z, Lubeck A. Opportunities for better use of collective action theory in research and governance for invasive species management. Conserv Biol. 2019;33(2):275–87. https://doi.org/10.1111/cobi.13266.

Gurr GM, Wratten, SD, and Barbosa P. Success in conservation biological control of arthropods. In Biologicalcontrol: Measures of success. Dordrecht: Springer; 2000. p. 105-132.

Hennink MM. Focus group discussions. Oxford: Oxford University Press; 2013.

ICA. Statement on the Cooperative Identity, Report to the 31st Congress Manchester. Rev Int Cooperation. 1995; 88.3.

Isaac ME, Erickson BH, Quashie-Sam SJ, Timmer VR. Transfer of knowledge on agroforestry management practices: the structure of farmer advice networks. Ecol Soc. 2007; 12(2). https://www.jstor.org/stable/26267879.

Jain S. An empirical economic assessment of impacts of climate change on agriculture in Zambia (Policy Research Working Paper 4291). World Bank. 2007. http://hdl.handle.net/10986/7478.

Kansiime MK, Mugambi I, Rwomushana I, Nunda W, Lamontagne-Godwin J, Rware H, Phiri NA, Chipabika G, Ndlovu M, Day R. Farmer perception of fall armyworm (*Spodoptera frugiperda* JE Smith) and farm-level management practices in Zambia. Pest Manag Sci. 2019;75(10):2840–50. https://doi.org/10.1002/ps.5504.

Kenis M, Benelli G, Biondi A, Calatayud PA, Day R et al. Invasiveness, biology, ecology, and management of the fall armyworm, *Spodoptera frugiperda*. Entomologia Generalis. 2022. https://doi.org/10.1127/entomologia/2022/1659.

Klerkx LWA, Hall A, Leeuwis C. Strengthening agricultural innovation capacity: are innovation brokers the answer? Int J Agricultural Resour Gov Ecol. 2009;8(5/6):409–38.

Kruger H. Designing local institutions for cooperative pest management to underpin market access: the case of industry-driven fruit fly area-wide management. Int J Commons. 2016;10(1):176–99. https://doi.org/10.18352/ijc.603.

Leeuwis C. Communication for rural innovation. Rethinking agricultural extension. 3rd ed. Oxford: Blackwell Science; 2004.

Makondo CC, Chola K, Moonga B. Climate change adaptation and vulnerability: a case of rain dependent small-holder farmers in selected districts in Zambia. Am J Clim Change. 2014;3(4):388–403. https://doi.org/10.4236/ajcc.2014.34034.

Marshall GR, Coleman MJ, Sindel BM, Reeve IJ, Berney PJ. Collective action in invasive species control, and prospects for community-based governance: the case of serrated tussock (*Nassella trichotoma*) in New South Wales, Australia. Land Use Policy. 2016;56:100–11. https://doi.org/10.1016/j.landusepol.2016.04.028.

Meijer SS, Catacutan D, Ajayi OC, Sileshi GW, Nieuwenhuis M. The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-saharan Africa. Int J Agric Sustain. 2015;13(1):40–54. https://doi.org/10.1080/14735903.2014.912493.

Meinzen-Dick R, DiGregorio M and N McCarthy. Methods for studying collective action in rural development. Agric Syst. 2004;82(3):197–214. https://doi.org/10.1016/j.agsy.2004.07.006.

Menzler-Hokkanen I. Socioeconomic significance of biological control. In: Eilenberg J, Hokkanen HM, editors. An ecological and societal approach to biological control. Dordrecht: Springer; 2006. p. 13–25.

Öjermark P, Chabala C. The development of independent cooperatives in Zambia: a case-study (No. 8). Food & Agriculture Organisation; 1994.

Oliver PE, Marwell G. The paradox of group size in collective action: a theory of the critical mass. II. Am Sociol Rev. 1988;53(1):1–8. https://doi.org/10.2307/2095728.

Ostrom E. Governing the commons: the evolution of institutions for collective action. New York: Cambridge University Press; 1990.

Ostrom E, Ahn TK. The meaning of social capital and its link to collective action. In: Ostrom E and TK Ahn, editors Handbook of social capital: The troika of sociology, political science and economics. Edward Elgar Publishing; 2009. p. 17–35. https://doi.org/10.4337/9781848447486.

Ostrom E. A general framework for analyzing sustainability of socio-ecological systems. Science. 2009;325:419–22. https://doi.org/10.1126/science.1172133.

Ostrom E. Analyzing collective action. Agric Econ. 2010;41(1):155–66. https://doi.org/10.1111/j.1574-0862.2010.00497.x.

Paini DR, Sheppard WA, Cook DC, de Barro PJ, Worner SP, Thomas MB. Global threat to agriculture from invasive species. Proc Nat Acad Sci USA. 2016;113(27):7575–9.

Parisi D, Taquino M, Grice SM, Gill DA. Civic responsibility and the environment: linking local conditions to community environmental activeness. Soc Nat Resour. 2004;17(2):97–112. https://doi.org/10.1080/08941920490261212.

Parsa S, Morse S, Bonifacio A, Chancellor TCB, Condori B, Crespo-Pérez V, Hobbs SLA, Kroschel J, Ba MN, Rebaudo F, Sherwood SG, Vanek SJ, Faye E, Herrera MA, Dangles O. Obstacles to integrated pest management adoption in developing countries. Proc Nat Acad Sci. 2014;111(10):3889–94. https://doi.org/10.1073/pnas.1312693111.

Pinto AC. Agricultural Cooperatives and Farmers Organizations—role in rural development and poverty reduction. 2009. http://www.un.org/esa/socdev/egms/docs/2009/cooperatives/Pinto.pdf. Accessed 19 Aug 2022.

Plessis HD, Schlemmer M, Van den J, Berg. The effect of temperature on the development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Insects. 2020;11(4):228. https://doi.org/10.3390/insects11040228.

Pratt CF, Constantine KL, Murphy ST. Economic impacts of invasive alien species on african smallholder livelihoods. Global Food Security. 2017;14:31–7. https://doi.org/10.1016/j.gfs.2017.01.011.

Ravnborg HM, De la Cruz AM, del Pilar Guerrero M, Westermann O. Collective action in ant control. 2000. (No. 577-2016-39142).

Rwomushana I, Bateman M, Beale T, Beseh P, Cameron K, Chiluba M et al. Fall armyworm: Impacts and implication for Africa. Evidence Note Update, CAB International. 2018. Available at https://www.invasive-species.org/wp-content/uploads/sites/2/2019/02/FAW-Evidence-Note-October-2018.pdf.

Sieber SS, Silva TCD, Campos LZDO, Zank S, Albuquerque UP. Participatory Methods in Ethnobiological and Ethnoecological Research. In: Albuquerque UP, Cruz da Cunha LVF, Paiva de Lucena RF and RR Nóbrega Alves, editors. Methods and Techniques in Ethnobiology and Ethnoecology. New York: Springer Protocols. Humana Press; 2014. p. 39–58.

Stallman HR. Ecosystem services in agriculture: determining suitability for provision by collective management. Ecol Econ. 2011;71:131–9. https://doi.org/10.1016/j.ecolecon.2011.08.016.

Stallman HR, James HS Jr. Determinants affecting farmers' willingness to cooperate to control pests. Ecol Econ. 2015;117:182–92. https://doi.org/10.1016/j.ecolecon.2015.07.006.

StataCorp. Stata Statistical Software: Release 17. College Station. TX: StataCorp LLC; 2021.

Swanson BE, Claar, JB. Defining extension Agricultural extension: A reference manual. Alternative models and recent trends in organizing agricultural Extension. Food and Agriculture Organization of the United Nations. Rome. 1984.

Tafesse S, Damtew E, van Mierlo B, Lie R, Lemaga B, Sharma K, Leeuwis C, Struik PC. Farmers' knowledge and practices of potato disease management in Ethiopia. NJAS Wageningen Journal of Life Sciences. 2018;86–87:25–38. https://doi.org/10.1016/j.njas.2018.03.004.

Tafesse S, Lie R, van Mierlo B, Struik PC, Lemaga B, Leeuwis C. Analysis of a monitoring system for bacterial wilt management by seed potato cooperatives in Ethiopia: challenges and future directions. Sustainability. 2020;12(9):3580–0. https://doi.org/10.3390/su12093580.

Tambo JA, Day RK, Lamontagne-Godwin J, Silvestri S, Beseh PK, Oppong-Mensah B, Phiri NA, Matimelo M. Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa an analysis of farmers' control actions. IJ Pest Manag. 2019. https://doi.org/10.1080/09670874.2019.1646942.

Tiwari A, Russpatrick S, Hoehne A, Matimelo SM, Mazimba S, Nkhata I, Osbert N, Soloka G, Winters A, Winters B, Larsen DA. Assessing the impact of leveraging Traditional Leadership on Access to Sanitation in Rural Zambia. Am J Trop Med Hyg. 2017;97(5):1355–61. https://doi.org/10.4269/ajtmh.16-0612.

Wakefield SE, Elliott SJ, Cole DC. Social capital, environmental health and collective action: a Hamilton, Ontario case study. Can Geographer/Le Géographe Canadien. 2007;51(4):428–43. https://doi.org/10.1111/j.1541-0064.2007.00190.x.

Wilson LJ, Whitehouse MEA, Herron GA. The management of insect pests in australian cotton: an Evolving Story. Ann Rev Entomol. 2018;63(1):215–37. https://doi.org/10.1146/annurev-ento-020117-043432.

White B. Biological Control of Insects Pests. Waltham Abbey: ED-Tech Press; 2019.

Wyckhuys KAG, Lu Y, Morales H, Vazquez LL, Legaspi JC, Eliopoulos PA, Hernandez LM. Current status and potential of conservation biological control for agriculture in the developing world. Biol Control. 2013;65(1):152–67. https://doi.org/10.1016/j.biocontrol.2012.11.010.

Yang Y, Li Y, Wu Y. Current status of Insecticide Resistance in *Helicoverpa armigera* after 15 years of Bt Cotton planting in China. J Econ Entomol. 2013;106(1):375–81. https://doi.org/10.1603/EC12286.

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