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RESEARCH

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Farmer perception of impacts of fall armyworm (*Spodoptera frugiperda* J.E. Smith) and transferability of its management practices in Uganda

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Abstract

Background The Fall armyworm (FAW) *Spodoptera frugiperda* (Lepidoptera: Noctuidae) is now established across the African continent and is a highly polyphagous and destructive pest of many crops. In Uganda, FAW has become the major maize pest, causing heavy damage especially on shoots and growing points. The objectives of this study were to: (i) document local farming practices that have been useful to manage FAW, (ii) establish farmers' perspective on the time of FAW's arrival to their localities, (iii) investigate the economic impact (yield) of FAW to maize farmers, (iv) establish the farmers' perception on the current status of the FAW, and (v) document alternative practices used to manage the FAW and the perceived efficacies.

Methods A questionnaire survey was undertaken in November 2020 in Kamuli and Namutumba districts of Uganda and 99 farmers were interviewed to understand their profiles and perceptions about the FAW. A descriptive analysis of this data was undertaken to establish the socio-economic profiles and perceptions of the farmers.

Results Farmers' education levels in the two districts ranged from basic (completed primary education) to advanced (completed University degree), with most farmers having 10–30 years experience in growing maize ($F = 20.8$; $df = 3,7$; $P = 0.0067$), and with mainly small- and mid-sized production scales ($F = 436.2$; $df = 2,5$; $P = 0.0002$). Famers in Kamuli (98%) and Namutumba (96%) reported 25–50% yield losses due to FAW infestation that negatively impacted their income. We found a significantly higher percentage of farmers (84% and 92% in Kamuli and Namutumba districts, respectively), could correctly identify the FAW by its appearance ($P < 0.0001$). While FAW was officially reported in Uganda in 2016, farmers confirmed noticing damage symptoms similar to those caused by FAW as early as 2013 and 2014 in Namutumba and Kamuli districts, respectively. 98% of the farmers in Kamuli and 96% of those in Namutumba strongly agreed that FAW infestation reduced their income, while 74% in Kamuli and 86% in Namutumba also strongly considered the FAW as a threat to maize production ($P < 0.0001$). The majority of farmers (64% in Kamuli, 82% in Namutumba) still considered the FAW to be a very serious challenge to maize production in their localities, six years since officially being reported in Uganda. To manage the FAW, 84% and 90% of Kamuli and Namutumba respondents respectively, predominantly use chemical control methods. Other methods used also included cultural control practices (i.e., by regular weeding and handpicking), while the use of biological extracts (pepper, tobacco, Aloe-vera, Lantana, sisal) was evident though not common. Pheromones and biological control methods to manage FAW were

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not reported, although a farmer in Kamuli district reportedly observed weaver birds (*Ploceus* spp.) predating on the FAW in maize. A small number of farmers (ca. 4%) in both districts reportedly took no intentional action against FAW.

Conclusions The farmers believe they can manage FAW if they have the appropriate and efficacious chemical insecticides as they are able to correctly apply them and follow recommended procedures. The farmers advocated for an area-wide approach as one of the best alternatives to manage this invasive pest.

Keywords Fall armyworm, Cultural pest management practices, Invasions, East Africa, Small scale maize production

Introduction

The Fall armyworm (FAW) (*Spodoptera frugiperda* J.E. Smith) (Lepidoptera: Noctuidae) is a highly polyphagous and destructive agricultural pest with a wide host range (>100 plant species that include cereals, legumes, cotton, potato, banana, vegetables, and grasses (Casmuz et al. 2010; Montezano et al. 2018). Native to the North, Central, and South Americas, the FAW was reported in western Africa in 2016 (Goergen et al. 2016) and by 2018, it was reported also in at least 44 African countries that included almost all of the sub-Saharan African nations (Rwomushana et al. 2018; Uzayisenga et al. 2018) and from Egypt in northern Africa (e.g., IPPC 2019), the Middle East and the Indian sub-continent, and China (Tay and Gordon 2019). The FAW has also been reported in the Near East and Asian/Southeast Asian countries including India (Ganiger et al. 2018; Sharanabassappa et al. 2018; EPPO 2019), Taiwan (IPPC 2019a; Shrikanth 2019), Japan, Myanmar, Vietnam (Vu 2008; Hang et al. 2019; IPPC 2019b; Rane et al. 2023), Indonesia (Bauventura et al. 2020), Papua New Guinea (Tay et al. 2023a), Philippines (Navasero et al. 2019), before being detected in Australia by February 2020 (IPPC 2020; Rane et al. 2023).

In East Africa and much of Southeast Asia, agriculture remains a major sector supporting the livelihoods of farm households, for example, in SE Asia, it accounted for about 40% of employment according to 1999/2001 and 2009/2011 FAO data (FAO 2019), while in sub-Saharan Africa, agriculture continues to provide more employment than any other sector, with more than 50% according to the 2009/2011 data (FAO 2019). However, in both of these regions, agriculture is also adversely affected by climate change which in turn affects the outbreak of crop pest populations (Bryan et al. 2013; Deutsch et al. 2018). Moreover, cereal production (with maize, rice and wheat as major crops) is greatly affected by the fall armyworm that recently invaded the regions.

In Africa, FAW consumes a wide variety of cereal crops, particularly maize which is the major staple grown by most farmers (FAOSTAT 2016). The FAW is currently a threat to food security and incomes and continues to threaten the livelihoods of millions of people as it has led to increased production costs and hinders trade between countries. The FAW causes especially severe damage to maize, feeding on virtually all parts of the plant, resulting in total crop failure (De Almeida Sarmento et al. 2002). In Africa, the potential yield reduction due to the FAW has been estimated to range from 8.3 to 20.6 tonnes/ha per year when no control measures were applied (Abrahams et al. 2017).

In Uganda, maize is one of the most important cereal crops and smallholder farmers usually engage in maize growing for food, as a cash crop, and as an important export crop. Over the years, production of maize increased from 2.8 million metric tonnes in 2015 to 4 million metric tonnes in 2017 (MAAIF 2018a) as a result of the increased demand for maize and other maize products, and the favourable climate that enables two cropping seasons in a year. Production of maize in Uganda was increased to supply neighbouring countries (i.e., Kenya, Tanzania, Rwanda, South Sudan, D.R. Congo) where it is a staple food for human consumption (e.g., with Kenya having an annual demand of 60,000 metric tonnes). Maize yields in Uganda (i.e., production, productivity and quality) have remained relatively low at 2.2–2.5 metric tonnes/ha (compared to the potential of 8 metric tonnes/ha) as a result of several biotic and abiotic factors that included pests and diseases, declining soil quality, drought stress, and inadequate extension services (MAAIF 2018a). The quality standards are also generally low, with high post-harvest losses during transportation, storage, and processing, while aflatoxin contamination reduces its competitiveness for access to regional markets.

Maize is attacked by numerous pests and diseases during the growing cycle, with infestation level and incidence dependent on weather factors, soil conditions, interactions with other arthropod species, and the level of resistance/susceptibility of the maize varieties. Pests of maize include cereal stemborers/the maize stalk borer *Buseola fusca*, the spotted stem borer *Chilo partellus*, the African pink borer *Sesamia calamistis*, cutworms, termites, maize weevils, and the recently established FAW. Traditionally, the two main maize pests in Uganda were *C. partellus* and *B. fusca* (Matama-Kauma et al. 2007). Elsewhere in Africa, *C. partellus* was the most important lepidopteran pest (e.g., Sohati et al. 2002; Cugala and

Omwega 2001; Wale et al. 2006), with its impact managed to a low level through the use of biological control (Sohati et al. 2002; Matama-Kauma et al. 2007; Wale et al. 2006). The FAW in Uganda was confirmed via molecular diagnostics from field-collected samples in May/June 2016 (Otim et al. 2018). Despite a percentage increase in numbers of farmers involved in maize production from 85 to 92% from 2014 to 2015, there was a drastic reduction in numbers of farmers producing maize in 2016 and 2017 to 81.5% which was attributed, in part, to both FAW (33%) and drought (23%) (NARO-ATAAS 2018).

Since its invasion, the major form of control advocated in African countries has been the use of insecticides. Due to the devastating effect of this invasive pest, and based on infestation rates, governments prioritised pesticide usage as an immediate response and procured pesticides for distribution (MoAIWD 2020; MAAIF 2018a). Governments raised awareness about the pest and provided support to farmers with access to chemical insecticides. However, without adequate knowledge on the ecology and biology of the pest and sound knowledge on the optimal timing, and rate of insecticide application, inappropriate use (e.g., misuse, overreliance) of pesticides could result in increased production costs and could increase risks to growers, consumers and the environment (Yu 1991; Carvarlho et al. 2013; Gutireez-Moreno et al. 2019; Zhang et al. 2020). The integration of other non-chemical practices such as cultural, mechanical, physical, and biological control options is thus important for the sustainable management of the FAW.

This study sought to understand what measures and alternative management practices have been used by farmers in Africa (Uganda in particular) to control the FAW since its invasion. We also seek to document practices that have been useful in Africa to manage the FAW by small-scale farmers. Specifically, the study aimed to: (i) document practices used and perceptions on efficacies by farmers for the management of FAW, (ii) document the economic impact (yield and income) of FAW, (iii) establish the farmers' perception of the status of the FAW since its invasion, including an understanding of when farmers thought was the earliest notice of FAW in their regions, and (iv) explore the transferability of cultural management practices from Africa to other regions such as southeast Asia also impacted by the FAW.

Materials and methods

Study area and sample selection

This study was carried out in November 2020 in Kamuli and Namutumba districts, which are two maize growing districts located in eastern Uganda (Fig. 1). Within each district, the focus was put on sub-counties (administrative units) where maize growing was prominent - a selection of this was made purposively before the investigation with the help of agriculture extension agents within each district. In a sub-county, farmers were randomly picked based on sub-county records. A total of 50 farmers were selected for interviews per district.

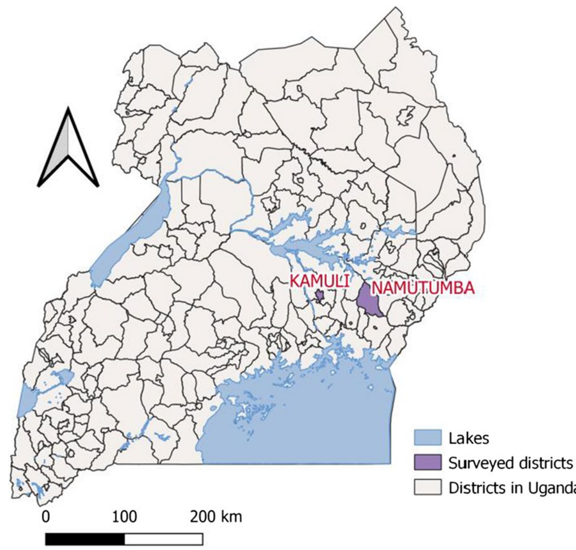

Fig. 1 Map of Uganda showing the locations of Kamuli and Namutumba districts where surveys were carried out

Questionnaire development and delivery

A 5-page anonymous questionnaire (~50 questions) (Additional file 1) was designed and used to assess farmers' socio-economic profiles, focussing on maize production. The questionnaire recorded farmers' gender and education levels, membership of farmer organisations, economic profile based on maize, awareness of FAW, knowledge of FAW damage and economic impact, ability to identify FAW at larval stages, practices for managing FAW, means of agricultural information exchange amongst farmers, and farmers' perception of ways-forward to manage the FAW challenge.

Farmers' economic profile based on maize focussed mainly on yield of maize per acre before and after FAW arrived. Assessment of farmers' understanding of the impact of FAW was based on whether they consistently and logically responded to questions on effects on income, production, yield and production costs. The maize production profile entailed establishing which maize varieties were grown before and after FAW invasion; the source of seed used during plantings; the farmers' experience (in years) of maize growing; production scale (i.e., small, medium, large); and the type of cropping system (whether organic or inorganic, monoculture or mixed). The scale of production (by area) was categorised as: (i) small, if the famer planted less than 4.94 acres; (ii) medium, if the farmer planted between 4.94 and 22.2 acres, and (iii) large, if more than 22.2 acres were planted.

The questionnaire also included questions to: (i) capture when farmers first noticed the FAW through recognising the specific symptoms and/or signs of crop damage in their fields that are now known to be due to FAW (MAAIF 2018b); (ii) the effectiveness (success/failure) of the methods deployed by farmers. Some questions were designed to understand whether farmers applied chemical insecticides to manage FAW, and if they did, further follow-up questions regarding method, frequency of application and gears used followed suit. For those that did not use insecticides, follow-up questions related to use could not apply, nevertheless, all this was kept in the data.

Data on maize yield/production was obtained for two seasons, before and after FAW invasion to understand the challenges attributed to FAW attack. This data was based on recollection of estimates by the farmer. Such quantification of yield estimates provided farmers' perceptions of the damage posed by the FAW.

The questionnaire was administered to the farmers in an interview to help understand the key questions that underpin the study objectives. Before each interview, the purpose of the survey was cleary articulated to each of the farmers, and thereafter consent sought for willingness to participate in the survey. The interviews were conducted in the local language of the area (i.e., Lusoga, for those that did not have good command of the English language) during the face-to-face interactions. For clarity, a mix of both Lusoga and English was used in other areas,. The scale of production was based on the acreage of maize planted by farmers in the last two seasons. We also assessed farmers' knowledge of the FAW through identification/recognition of its life stages, symptoms or damage, and through scouting for FAW in the farmers' field. Using a pictorial chart of insect larval developmental stages, farmers were also asked to identify which life stages they had seen commonly within their fields. This moment was also used to educate the farmers about the different stages of the FAW life cycle (some of which they had not seen before but were important for proper management of the FAW). The interviews which lasted averagely 45 min, included question time and writing/filling in responses in the questionnaire.

Data analysis

Descriptive statistical analyses were undertaken to calculate the frequencies, means, and percentages where appropriate, and when necessary, differences between variables of interest were determined by the use of chi-square and ANOVA tests.

Results

Gender profile of maize farmers

In Kamuli district, 24% of the farmers interviewed were female while 76% were male. In Namutumba, the majority (69.4%) were male while females were 30.6% (Table 1). The significantly smaller numbers of female respondents in both districts meant we are unable to disaggregate various attributes by gender.

Educational profiles

Generally, more than half of the maize famers in both districts were educated to and above secondary level by Uganda national standards, an equivalent of seven years of primary education, four years of ordinary level secondary education, which may also include two years of advanced level secondary education (UBOS 2006). Two fifths of farmers in each of the districts were educated to Primary level (Table 1). A very low number of farmers in each district had not undergone formal education (2% in Kamuli, 6% in Namutumba), and a few (8% in Kamuli, 10% in Namutumba) had tertiary education (Table 1).

Farmer experience in maize production

Farmer's experience in maize production within Kamuli district ranged from 4 to 50 years while it was 1 to 50 years in Namutumba. The majority of the farmers (i.e., 64% in Kamuli, 59% in Namutumba) reportedly had between 10 and 30 years' experience in growing maize ($P = 0.0067$)(Table 1). 28% (28%) of the farmers in Kamuli had between 31 and 50 years' experience, while in Namutumba district this was 16%.

Scale of maize production

Only 2% of farmers in the two districts were large-scale farmers growing more than 10 acres of maize, with the majority of the farmers participating in medium-scale (50% in Kamuli, 53% in Namutumba) or small scale farming (48% in Kamuli, 45% in Namutumba) ($P = 0.0002$) (Table 1).

Maize cropping system

The most common cropping systems amongst maize farmers in the two districts were either as inorganic monoculture maize (54% in Kamuli, 45% in Namutumba), or as inorganic mixed cropped maize (46% in Kamuli, 55% in Namutumba; Table 1). Under inorganic cropping, the farmers used chemical fertilizers to enhance crop growth, insecticides to reduce pests and diseases, herbicides to control weeds, as well as other cultural control techniques affordable to them such as hand weeding, crop rotation and mulching among

Table 1 Maize farmer's profiles from Uganda's Kamuli and Namutumba districts

Study variable	Kamuli (N = 50)	Namutumba (N = 49)	Chi-sq value/F-test
Gender profile of respondents (%)			
Female	12 (24%)	15 (30.6%)	$\chi^2 = 0$; df = 3; $P = 1$.
Male	38 (76%)	34 (69.4%)	
Educational level of farmers (%)			
Non-formal	1 (2%)	3 (6.1%)	F = 93; df = 3,7; $P = 0.0004$
Basic (elementary)	20 (40%)	20 (40.8%)	
Secondary	25 (50%)	21 (42.9%)	
Tertiary	4 (8%)	5 (10.2%)	
Farmers experience in maize production			
< 10 years	3 (6%)	12 (24.5%)	F = 20.8; df = 3,7; $P = 0.0067$
10–30 years	32 (64%)	29 (59.2%)	
31–50 years	14 (28%)	8 (16.3%)	
51–70 years	1 (2%)	0	
Membership to farmer organizations			
Yes	34 (68%)	27 (55.1%)	$\chi^2 = 0$; df = 3; $P = 1$.
No	16 (32%)	22 (44.9%)	
Source of seed			
Own saved seed	11 (22%)	13 (26.5%)	F = 0.83; df = 3,7; $P = 0.5419$
Government	5 (10%)	19 (38.8%)	
Retail agro-shops	21 (42%)	15 (30.6%)	
NGOs	13 (26%)	2 (4.1%)	
Scale of production			
Small	24 (48%)	22 (44.9%)	F = 436.2; df = 2,5; $P = 0.0002$
Medium	25 (50%)	26 (53.1%)	
Large	1 (2%)	1 (2%)	
Type of maize cropping systems			
Organic monoculture	0	0	F = 79.7; df = 3,7; $P = 0.0005$
Organic mixed cropping	0	0	
Inorganic monoculture	27 (54%)	22 (44.9%)	
Inorganic mixed cropping	23 (46%)	27 (55.1%)	
Farmers' ability to identify FAW			
True	42 (84%)	43 (91.7%)	F = 497.5; df = 3,7; $P < 0.0001$
False	2 (4%)	0	
No idea	2 (4%)	4 (8.2%)	
Only symptoms	4 (8%)	2 (4.1%)	

The values (percentages) provided in parenthesis within each column represent the proportion of respondents for a variable under study as a percentage of the total number of respondents interviewed

others. They either grew a single crop-maize (monoculture), or practiced mixed cropping/intercropping by growing more than one crop. Organic maize production was not found practiced anywhere by farmers in both districts. Organic farming as a practice usually combines a high level of conservation of biodiversity with environmental practices that preserve natural resources and rigorous standards for animal welfare. In such a system of production, pesticides and fertilizers are of natural origin as opposed to synthetics in conventional/inorganic farming.

Source of maize seed used in planting

Farmers obtained seed for planting from four major sources: (i) own-saved seed from previous harvests, (ii) from the government; (iii) from non-government organizations (NGOs), and (iv) purchased from retail agro-stockists. The majority of farmers in Kamuli (42%) obtained seed from agro-stockists and 26% from NGOs, this contrasted with farmers in Namutumba whereby 39% obtained their seed from the government and from retail agro-stockists (31%) (Table 1). In Kamuli, 24% of maize seed was of a local variety- soga - a farmer-adapted maize variety grown in the area for generations, while 77% of the maize seeds comprised improved varieties. In Namutumba, the local variety accounted for only 9% of the maize seeds planted while 91% were improved seed varieties (Additional file 2). Our survey also revealed that 22% of farmers in Kamuli and 27% of farmers in Namutumba re-used seeds from previous harvests.

Membership to farmer organizations

Asked as to whether they belonged to any farmers' groups/organizations, 68% of the farmers in Kamuli and 55% in Namutumba responded in the affirmative (Table 1). Farmer groups or organizations were more structured and formal (i.e., registered and legally recognised by local government authorities) in Kamuli than in Namutumba.

Total membership of these farmer organizations ranged from 8 to 4,000 farmers in Kamuli with just over half (55%) comprised of 10–30 members. In Namutumba district, membership ranged from 20 to 349 members. However, majority (62%) groupings comprised 20–30 members.

Year FAW was first noticed in the field

While the official report for FAW in Uganda was 2016, results of first notice of FAW symptoms and damage by farmers indicated the FAW was noticed at different times depending on the locality within the districts. In Kamuli district, 2% of the farmers noticed FAW damage and symptoms in 2014, 22% in 2015, 10% in 2016, 40% in 2017, 20% in 2018 while about 2% noticed it in 2019 and 2020 in their localities (Fig. 2). Within Namutumba district, 2% of farmers noticed FAW as early as 2013 while others continued to notice it in subsequent years; 8% noticed FAW in 2015, 22% in 2016, 41% in 2017, 21% in 2018 while 2% noticed it in 2019. Generally, the majority of farmers interviewed in the two districts noticed FAW damage in the year 2017. The survey also identified 2% of farmers in Kamuli had no idea when FAW invasion occurred (Fig. 2).

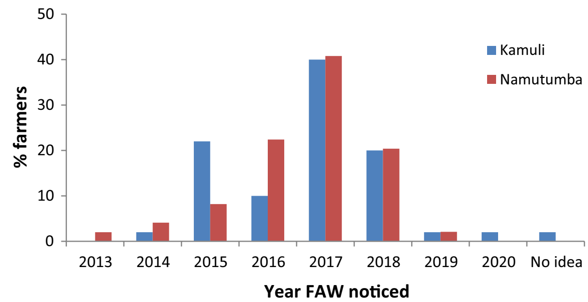

Fig. 2 The year when farmers first noticed symptoms and signs of *Spodoptera frugiperda* in their fields. Expressed as the percentage of respondents to our interview in each region of Uganda

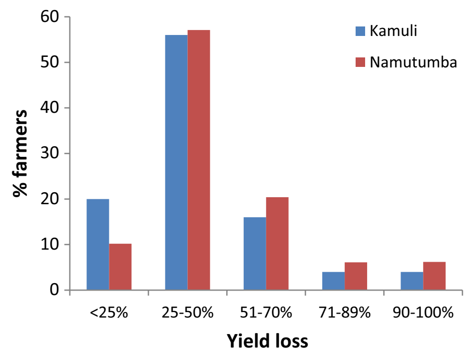

Fig. 3 Percentage of interviewed farmers who reported yield loss estimates attributable to FAW damage under different categories in the two districts of Uganda

Economic impact (yield loss estimates)

The impact of the FAW in terms of yield losses reported by farmers was relatively variable. While 20% of the farmers reported yield losses less than 25% in Kamuli district, the numbers were much less at 10% in Namutumba district (Fig. 3). In Kamuli, 56% of the farmers experienced yield losses of 25–50% as compared to 57% of the farmers in Namutumba who experienced similar magnitudes of yield loss. 16% of farmers in Kamuli and 20% of farmers in Namutumba reported yield losses to the magnitude of 51–70%. A few farmers though (4% in Kamuli and 6% in Namutumba) experienced 90–100% yield loss due to FAW (Fig. 3) on maize varieties Longe 5 and Soga in Kamuli, and Bazooka and Soga in Namutumba.

Generally, the highest percentage (~55%) of farmers reported 25–50% yield losses in both districts that reduced their income. The relationship between yield loss (FAW damage) and the variety of maize could not be easily established (as varieties were highly variable from farmer to farmer) but farmers reported local maize varieties (e.g., soga) being less susceptible to FAW than improved varieties. Even among the improved varieties, there was a lot of variability. Where farmers reported 25–50% yield loss for example, the main maize varieties planted at the time comprised 35% local, 66% improved varieties in Kamuli, and 21% local, 79% improved in Namutumba. Nonetheless, many improved maize varieties were used because they had better yield attributes while others additionally had the ability to control the witchweed *Striga hermonthica* rather than their ability to control FAW. Screening of local and improved maize varieties for resistance to FAW is therefore needed.

Farmers' perception of FAW

When asked whether FAW infestation reduced their income, 98% of the farmers in Kamuli and 96% of those in Namutumba strongly agreed with the statement, while 2% and 4% of farmers simply agreed with it in the two districts, respectively. Seventy four (74%) and 86% of the farmers in Kamuli and Namutumba, respectively, also strongly agreed that FAW was a threat to maize production in their respective areas/districts ($P<0.0001$). Additionally, 92% of the farmers in Kamuli and 98% of those in Namutumba acknowledged that FAW reduced maize yield ($P<0.0001$). Probed further to the effect that FAW reduced the cost of production, 82% of the farmers in Kamuli and 84% of the farmers in Namutumba strongly disagreed with it while 12% and 10% just disagreed ($P<0.0001$) (for Kamuli and Namutumba, respectively). About 2% in Namutumba district had no opinion about costs of production being lowered or increased by FAW infestation (Table 2).

The majority of farmers interviewed (64% in Kamuli, 82% in Namutumba) also considered the FAW to still be a very serious challenge to maize production in their localities (Fig. 4), while 22% and 16% of them considered it as serious but manageable if the right approaches and control operations were adopted and intensified.

Table 2 Kamuli and Namutumba districts' farmers' perceptions of the economic impact of *Spodoptera frugiperda* to their farm production

Study variable	Kamuli	Namutumba	Chi-sq value/F-test
FAW infestation reduces farmers income			
Strongly disagree	0	0	F = 1816.2; df = 4,9; $P<0.0001$
Disagree	0	0	
No opinion	0	0	
Agree	1 (2%)	2 (4.1%)	
Strongly agree	49 (98%)	47 (95.9%)	
FAW is a threat to maize production			
Strongly disagree	0	0	F = 109.97; df = 4,9; $P<0.0001$
Disagree	5 (10%)	1 (2.04%)	
No opinion	0	1 (2.04%)	
Agree	8 (16%)	5 (10.2%)	
Strongly agree	37 (74%)	42 (85.7%)	
FAW damage reduces maize yield			
Strongly disagree	0	0	F = 663.34; df = 4,9; $P<0.0001$
Disagree	0	0	
No opinion	0	0	
Agree	4 (8%)	1 (2%)	
Strongly agree	46 (92%)	48 (98%)	
FAW reduces maize production costs			
Strongly disagree	41 (82%)	41 (83.7%)	F = 2042.8; df = 4,9; $P<0.0001$
Disagree	6 (12%)	5 (10.2%)	
No opinion	0	1 (2.04%)	
Agree	2 (4%)	2 (4.08%)	
Strongly agree	1 (2%)	0	

The values (percentages) provided in parenthesis within each column represent the proportion of respondents for a variable under study as a percentage of the total number of respondents interviewed

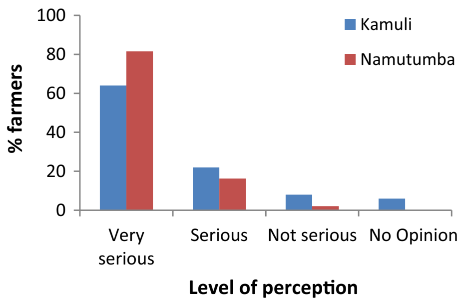

Fig. 4 Farmers levels of perception of the seriousness of the current *Spodoptera frugiperda* challenge to maize production in the two districts surveyed in Uganda

Farmers ability to identify FAW larvae and damage symptoms

An assessment of the level of knowledge to identify FAW in the field by a description of its appearance and by the symptoms of damage revealed that 84% of the farmers in Kamuli and 92% of the farmers in Namutumba could correctly identify the FAW by its appearance as compared to the 8% and 4%, respectively, who could only identify FAW by symptoms so caused (Table 1). Farmers at first were asked to describe what they observed as perceived symptoms of FAW damage, and later were shown photos of various life cycle stages of the FAW and damage symptoms, without telling them so they could identify what they had seen and observed in their fields.

About 4% of the farmers in Kamuli could not identify the FAW correctly (i.e., the farmers failed to describe FAW appearance/site where found on plant and their description of damage symptoms was also vague), while 4% of the farmers in Kamuli and 8% of those in Namutumba had no idea as to either the appearance or the damage symptoms caused by FAW on maize.

FAW Farmer management practices

To manage the FAW, 84% of the respondents in Kamuli and 90% of those in Namutumba reported to use chemical insecticides (Table 3) with varying levels of successes and failures. Besides chemical insecticides, 42% of farmers in Kamuli and 44% of those in Namutumba managed FAW by the cultural practice of regular weeding. Some farmers (24% in Kamuli, 31% in Namutumba) tried physical and manual removal (i.e., by hand picking) of FAW larvae from infested maize stands and cobs. However, the method was very laborious and difficult to sustain especially for farmers with fields beyond one acre. About 4% of farmers in both Kamuli and Namutumba reportedly took no intentional action against FAW, citing reasons such as poverty, cost of insecticides, being overwhelmed by the devastating effect of the FAW and abandoned the maize fields since they could not access or afford effective control options.

The majority of farmers in the two districts (44% in Kamuli, 43% in Namutumba) used Roket (a.i.: profenofos (40%), cypermethrin (4%)) as the main insecticide against the FAW. The second most commonly used insecticide in Kamuli was Striker (a.i.: lambda-cyhalothrin and Thiamethoxam, 10%) and was used by 20% of the farmers, while in Namutumba, 16% of the farmers used Eminent (a.i.: emamectin benzoate, 5%) as the second most widely used insecticide, followed by Dudu Cyper (a.i.: cyptermethrin, 12%) and Striker (a.i.: lambda-cyhalothrin and Thiamethoxam, 10%). The World Health Organization (WHO) classifies profenofos/cypermethrin as class II (moderately hazardous) pesticides, lambda cyhalothrin as class III (slightly hazardous) pesticides, while emamectin benzoate is class IV (unlikely to cause acute effects in normal use) pesticide (Table 3).

Table 3 List of insecticides used against *Spodoptera frugiperda* by farmers in the two districts surveyed in Uganda

Trade name	Active ingredient (a.i)	WHO class*	Recommended dosages	
			In 15 L	In 20 L
Roket	Profenofos 400 g/l + Cypermethrin 40 g/l	II	15–40	20–50
Amdocs 3EC	Abamectin 18 g/l + Emamectin benzoate 12 g/l	II	25–30	30–50
Profecron	Profenofos 400 g/l + Cypermethrin 40 g/l	II	15–40	20–50
Dudu acelamectin	Abamectin 18 g/l + Acetamiprid 30 g/l	II		
Duducyper	Cypermethrin 50 g/l	II		
Tafgor	Dimethoate 400 g/l	II		
Striker	Lambdacyhalothrin 106 g/l + Thiamethoxam 141 g/l	III	15–20	20–25
Laraforce	Lambdacyhalothrin 25 g/l	III		
Eminent	Emamectin benzoate 50 g/kg	IV	4 tea spoons (6 g/tea spoon)-6-9mls	5 tea spoons 8–12 mls

* WHO classification: II = moderately hazardous; III = slightly hazardous; IV = unlikely to present acute hazard in normal use

Table 4 Parameters on farmers' method and frequency of insecticide application for *Spodoptera frugiperda* management in the two districts of Uganda

Study variable	Kamuli	Namutumba	Chi-sq value/ F-test
Chemical use within season			
One chemical at a time	40 (80%)	43 (87.7%)	$\chi^2 = 0$; df = 3; P = 1.
Two or more at once	4 (8%)	2 (4.1%)	
Frequency of use			
Once	9 (18%)	4 (8.2%)	F = 26.23; df = 4,9; P < 0.0015
Twice	13 (26%)	16 (32.7%)	
Thrice	18 (36%)	16 (32.7%)	
Four times	1 (2%)	2 (4.1%)	
No schedule	2 (4%)	1 (2%)	
Spraying equipment (Backpack sprayer)			
Yes	31(62%)	30 (61.2%)	$\chi^2 = 0$; df = 3; P = 1.
No	13 (26%)	16 (32.7%)	
Protective gear			
Yes	22 (44%)	9 (18.4%)	$\chi^2 = 0$; df = 3; P = 1.
No	23 (46%)	37 (75.5%)	
Protective gear use			
Yes	20 (40%)	3 (6.1%)	$\chi^2 = 0$; df = 3; P = 1.
No	25 (50%)	43 (87.8%)	
Method of spraying			
Random spraying	1 (2%)	0	$\chi^2 = 0$; df = 3; P = 1.
Targeted spraying	42 (84%)	43 (87.8%)	
Noticed chemicals failing[1]			
Yes	28 (56%)	28 (57.1%)	F = 331.4; df = 2,5; P < 0.0003
No	17 (34%)	15 (30.6%)	
No idea	5 (10%)	4 (8.2%)	

[1] By chemical failing, the farmers meant that the FAW could survive and thrive after application of the chemical, i.e., chemical was ineffective to control FAW. Note that application of ≥ two times per season is considered as 'high dose' usage. The values (percentages) provided in parenthesis within each column represent the proportion of respondents for a variable under study as a percentage of the total number of respondents interviewed

Method of application

Most farmers (84% in Kamuli, 88% in Namutumba; Table 4) used targeted spraying (by backpack sprayer) into the maize funnel, as opposed to general spraying, to directly target where the caterpillars resided. All plants were targeted. Eighty (80%) of the farmers in Kamuli and 88% in Namutumba applied only one chemical insecticide at a time within the cropping season (Mar–Jul, Aug–Dec), while 8% and 4% of farmers in both districts, respectively, attempted to spray more than once within the season. Most farmers attempted to spray either two or three times, usually after two weeks (Table 4). At least 60% of farmers interviewed had spraying equipment. However, the majority (46% in Kamuli and 76% in Namutumba) did not have protective gear. Of those that had protective gear, their use was low, for example, 50% of the farmers in Kamuli and 88% of those in Namutumba did not use them while spraying the chemicals. Twenty eight (28%) of farmers in Kamuli and 29% in Namutumba reported to use protective foot ware (i.e., gumboots) and also handkerchiefs as improvised face masks. There was no use of gloves and work suits reported. Even when farmers were aware of potential side effects on their health (e.g., skin irritation, headache) as consequences of not using protective gear, farmers simply reported that it was expensive for them.

Cultural and biological methods for FAW management

Besides chemical control of FAW, other methods used were predominantly cultural methods and the use of biological extracts. Cultural methods included timely and adequate land preparation (a primary cultivation followed by secondary cultivation after 2–3 weeks interval, before planting), garden sanitation (keeping garden devoid of refuse), crop rotation, intercropping, hand picking, early planting, use of organic manure as fertiliser, and a habitat management practice commonly known as push-pull strategy (Cook et al. 2007). Originally developed for the control of cereal stem borers (Khan et al. 2000), push-pull strategy involves intercropping maize (or another cereal crop) with a legume crop (e.g., *Desmodium*) and this is simultaneously intercropped with nappier grass at the periphery (edges) of the garden. The *Desmodium* intercrop acts to repel (i.e., 'push') pests away from the maize, while the nappier grass at the edges of the garden 'pulls' the pests away from the maize. A farmer in Kamuli reported that the method was 100% effective in controlling FAW in his field while another reported 70% effectiveness.

Biological control of FAW was not practiced by farmers although one farmer in Mukokotokwa (Kamuli district) reportedly observed weaver birds (*Ploceus* spp.) predating on FAW larvae in a maize field. Biological-based methods for FAW control involved the use of animal and plant products. Farmers that reported using biological-based products were 20% in Kamuli and 12% in Namutumba. The animal product was typically urine (animal/human urine), while plant extracts were predominantly from *Aloe vera*, tobacco (*Nicotiana tabacum*), chili pepper (*Capsicum* spp.), *Lantana camara* and the Neem tree (*Azadirachta indica*) used alternately or in combination with ash (perceived as catalyst, but that it also stops worms from feeding) (see Additional file 3). Of the farmers that used these extracts, 40% in Kamuli and 33% of those in Namutumba reported varying efficacy levels (50–95%) but generally, they considered them effective in controlling the FAW albeit limited only to small-sized gardens due to difficulties in ascertaining the right quantities to use.

Farmer's sources of FAW information

An assessment of how farmers accessed and/or shared information on the FAW revealed two main sources: (i) farmer to farmer exchanges/farmers groups, and (ii) TV/radio programs/talk shows (Fig. 5). In Kamuli, farmers

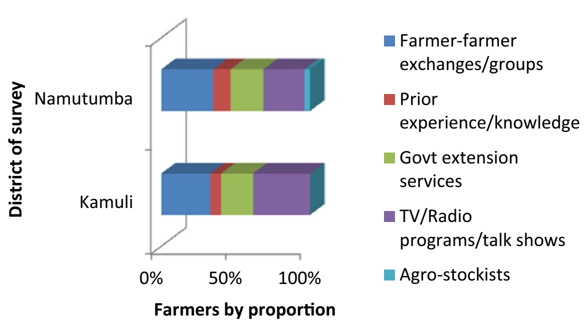

Fig. 5 Sources of farmer information on *Spodoptera frugiperda* management in the two districts of Uganda

relied mostly on TV and radio programs (39%), followed by farmer-farmer exchanges either individually or in farmer groups (33%), while others relied on the government extension service available in the district (21%). Seven (7%) of the farmers interviewed relied on knowledge gained from previous experiences on other common native and non-native pests. Within Namutumba district, farmer-farmer exchanges formed the main source of information (36%), followed by TV/radio programs/talk shows (29%), government extension service (23%), prior experience (12%), and agro-stockists (4%).

While farmers used all channels to receive information on FAW, much of the sharing of agricultural information was through exchanges between farmers either individually or in groups. A number of NGOs allied to agriculture in the two districts have organized farmers in groups, through which they could share a wide range of information on agronomic practices including pest and disease management, and post-harvest and marketing strategies. In the two districts, none of the people interviewed had ever heard or even used the FAO's FAW app 'FAMEWS'.

Discussion

This study documented practices that have been successful and unsuccessful in managing the FAW since its invasion of Africa using Uganda as a case study. Through the interviews we document the diversity of actions employed by farmers to combat FAW, and their perception on whether pest control efforts are successful. This knowledge is critical for designing sustainable pest management strategies for this highly destructive agricultural pest that may have a high chance of being adopted by farmers. This work also provides insights that might be useful in other farming contexts where FAW has only just arrived or is yet to invade.

After its invasion, many African Governments provided and distributed pesticides to farmers, and this approach continued as the first line of control measure against the FAW. The farmers provided more information on the type of chemical insecticides used, doses, spray regimes, and how they handled the pesticides, although there was limited consideration towards safety of farm applicator and environmental risks. Farmers also tried to use inflated dose rates and high doses of some pesticides through increased frequency of application, while others combined pesticides (of similar or different active ingredients) in a desperate attempt to control FAW but instead noticed failure. While rotating pesticides with different active ingredients would be a good practice to minimise the development of insecticide resistance in FAW, combining could easily lead to the development of either multiple or cross resistance depending on the nature of insecticides involved.The 56% of farmers in

Kamuli and 57% of farmers in Namutumba who noticed chemical efficacies failing might be attributed to some of the above reasons. The application of insecticides at high frequencies could lead to the development of resistance in the FAW population either singularly or in combination with other insecticides as it increases the selection pressure. The method of application of these chemicals and the frequency of use may also negatively influence efficacy. Some insecticdes cause mortaility after contact with the larvae and this can be hard if the larvae shelter in the maize whorl. Pesticide use and application, therefore, needs to be re-evaluated and research on the optimal rates and timing of application for Ugandan farmers needs to be conducted and communicated. Frequent use of insecticides may have serious implications on beneficial insects, environment, human and animal health, and promote secondary pest outbreaks, in addition to promoting rapid evolution of insecticide resistance in local pest populations (Devine and Furlong 2007). In this study, some insecticides (such as lambda-cyhalothrin and emermectin benzoate) found commonly used by the farmers against FAW in the distrcits and considered effective, are also considered high risk to both human and environmental health (Jepson et al. 2020). The Government needs to sensitize farmers to regulate their use (dose rates vs. frequency of application), regulate access along the supply chain and find better safe alternatives in order to mitigate some of the health and environmental risks associated with their use.

Given the propensity for FAW to migrate long distances, local insecticide misuse and the development of resistance could have an impact on the management of the pest in neighbouring regions and countries, as well as potentials of re-introduction of insecticide resistant individuals back to native populations due to global trade (Tay and Gordon 2019; Tay et al. 2021). It is therefore important that some research to test for resistance traits in local field populations of FAW is undertaken to document the extent of resistance and prepare neighbouring regions.

Besides chemical insecticides, some cultural practices such as frequent weeding (70% in Kamuli, 63% in Namutumba), intercropping (48% in Kamuli, 55% in Namutumba) and trap cropping (2% in Kamuli, none in Namutumba) were used by smallholder farmers to manage FAW. The push-pull method, which involves intercropping maize with some leguminous crop is effective against various cereal stemborers when compared to monoculture maize (Midega et al. 2018), was noted as effective also against the FAW by some farmers from Kamuli (4%). However, in another study, Baudron et al. (2019) intercropped maize with other legumes such as cowpea, groundnut, and common bean instead of *Desmodium* spp. but this did not appear to reduce FAW damage. Although the potential to use a push-pull system to control FAW appears high, research is needed to determine which companion crops (trap/repellent crops) would be the most efficient in controlling the FAW and also the most acceptable for use by smallholder farmers. The push-pull approach, which is also a habitat management system has great potential for transferability to farmers in, e.g., southeast Asia once the species compatible with the crop system in that region are identified. In general, push-pull systems have been found to increase plant diversity and could encourage and conserve diversity of natural enemies in the agricultural landscape (Day et al. 2017).

Other non-chemical practices such as the use of ash, urine, sand, soil, and plant extracts (such as *Capsicum* spp., *Lantana camara*, *Azadirachta indica*, *Aloe vera*, *Agava sisalana*) represented cheaper options for poor farmers (Stokstad 2017; Kumela et al. 2018) but have shown conflicting results for the management of FAW, with some farmers noting these as labour intensive approaches. Phambala et al. (2020) found potential bioactivity of some of these extracts against the FAW with approximately 50% mortality reported for *A. indica* and *N. tabacum*, and <40% recorded for *A. vera*. In Ethiopia, Sisay et al. (2019) also reported high activity of some of these extracts including *L. camara*, *A. indica, N. tabacum* and *Jatropha gossypifolia* against the FAW. In Brazil, Silva et al. (2015) found aqueous extracts of neem seed cake to be effective against the FAW in maize. Knowledge and experiences on the use of plant extracts with potential bioactivity against the FAW can easily be transferred for the benefit of farm households while encouraging trials on locally available plant products from these areas. Neem extracts (*A. indica*) for example, have widely been used across the world. Cultural approaches and options involving biological extracts typically have lower associated health and environmental risks (Prasanna et al. 2018). These and many other practices that show potential (given the perceptions of the farmers) require local testing and validation before they could be promoted for use and adoption by the wider farming community across the recent invasive ranges of FAW.

In this study, the yield loss estimates experienced by 56% of farmers in Kamuli and 57% of those in Namutumba districts due to FAW were in the range 25–50% while 16% and 20% of farmers in those very areas estimated losses in the range 51–70%. These estimates could not be verified in farmers fields through direct field obervations as it was slightly off-peak the maize season but also because it was beyond the scope and budget for this study. However, the estimates are comparable to those reported from other countries in Africa. For example, in Kenya, De Groote et al. (2020) reported losses of 54% and 42% to be due to FAW as reported by 63% and 83% of the farmers in 2017 and 2018, respectively. In Ghana and Zambia, socio-economic surveys (Abraham et al. 2017; Kumela et al. 2018) reported yield losses in maize due to FAW to be 40% (range 25–50%) and 45% (range 22–67%) in the two countries, respectively. Much recently, Tambo et al. (2021) has reported about 11% of livelihoods in Zambia affected by FAW leading to severe food shortages, and these studies established that in severe cases of the pest, a decrease of 44% in per capita household incomes was experienced with 17% of farmers likely to go hungry.

Although many farmers strongly agree that the FAW is still a challenge to maize production, the majority are confident that they now have several management and control options to reduce the damage posed by the FAW. With adequate education and support, they believe the FAW will be contained through area-wide approaches. It is because of this that some farmers strongly disagreed with the statement that FAW is a threat to maize production in their regions, reasoning that they only thought so in the beginning when they had no known control options. There is, therefore, a need for continuous farmer education and sharing of knowledge and experiences on best FAW management practices taking advantage of established information-sharing channels (e.g. farmer-farmer exchanges, radio and television talk shows).

In the two districts surveyed, farmers were not aware of the existence of the FAW app 'FAMEWS' as a source of information, and few farmers (< 1%) had smart phones or internet access. The use of such tools (FAW app) and internet access could help strengthen control as farmers may be able to access more relevant information on FAW management practices. Although officially reported in 2016, some farmers reported they noticed the FAW symptoms and damage as early as 2013 in Namutumba, and 2014 in Kamuli. At these times, farmers mentioned they first confused it with the cereal stemborers but subsequent observations and scrutiny revealed that this pest (FAW) was more devastating than the existing cereal stemborers. While the timing of farmers observation conflicted with that of the official report in 2016, earlier reports of FAW in the Old World are known (e.g., Vu 2008; Nguyen and Vu 2009; see also 'Interception Records' in Gilligan and Passoa 2014; see also review by Tay et al. 2023b). Given the severity of FAW damage, it became evident that this was a new and different invasive species. Some farmers could recall the exact period when they first noticed such devastating damage and symptoms given their current level of awareness, experience, and ability at identification. They were therefore confident that they noticed FAW earlier than officially reported. An earlier report (NARO-ATAAS 2018) also points to farmer's detection of symptoms and damage by FAW as early as 2014 in eastern as well as northern Uganda corroborating present results.

Conclusions

Our interviews have shown that Ugandan farmers believe they can manage FAW if they have the correct and efficacious insecticides as they are able to correctly apply them. Some of them disagreed that FAW is a threat to maize production and therefore perceived that soon they will be able to achieve total control of this pest (Table 2). Given the devastating level of damage and losses earlier experienced by farmers during the invasion of FAW in Africa, the farmers' current attitudes and confidence is a positive sign. However, we must remain vigilant that this confidence is not undermined by the development of widespread resistance to popular insecticides. The continuous sharing and transfer of this experience, knowledge and technologies by farmers coupled with more research efforts to develop novel control options, including exporing efficacies of endemic ethnomopathogenic fungi, will contribute to the development of long-term sustainable management of the FAW.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43170-023-00150-w.

Additional file 1: Questionaire used to assess farmers' socio-economic profiles on maize production in the two districts in Uganda.

Additional file 2: Maize varieties reported grown by farmers in Kamuli and Namutumba districts in Uganda.

Additional file 3: A detailed description of farmers' FAW cultural and biological-based management practices from the two districts surveyed in Uganda.

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Author contributions

AK, WTT, TW conceptualized the idea; WTT obtained funding, AK carried out the investigations. AK analysed the data and wrote the first draft manuscript, AK, WTT, MHO, TM reviewed the manuscript. All authors read and approved the final manuscript.

Availability of data and materials
Relevant data has been analysed and included in the paper and other data included as supplementary materials.

Declarations

Ethics approval and consent to participate
Consent to participate in this study was obtained from the individual farmers in selected districts of Uganda prior to the start of the survey. The questionnaire used during the surveys was reviewed and approved by CSIRO Ethics Committee before conducting the investigations.

Consent for publication
Not applicable.

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

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