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Smallholder farmers' knowledge, perception and management of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on *Zea mays* at irrigation schemes in Limpopo province, South Africa

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ABSTRACT

The fall armyworm (*Spodoptera frugiperda*) was first detected in Limpopo province, South Africa, during the 2016/2017 cropping season and continues to cause significant damage to maize production in the region. Despite the significant damage caused by *S. frugiperda* to maize, there is a lack of documented information on smallholder farmers' responses and control practices in South Africa. This study investigated smallholder farmers' knowledge, perceptions, and management practices of *S. frugiperda* at the Dzindi and the Tshiombo irrigation schemes in Limpopo province, South Africa. In this study, an irrigation scheme refers to a communal water distribution system that channels water from a river to multiple plots under smallholder cultivation through furrows or canals. Data were collected through 16 focus group discussions with farmers from the two irrigation schemes. A total of 118 farmers participated in the interviews. Each was assigned a unique identifier, which allowed for the recording and analysis of individual responses where applicable. Thematic analysis was used to identify and summarize common themes from participants' responses, while descriptive analysis using frequencies and percentages was employed to present the responses quantitatively. Farmers perceived *S. frugiperda* as the most destructive insect pest, yet lacked knowledge of its biology, being unable to identify its eggs, pupae, or adult moths. Control was largely through insecticide use. At the Dzindi irrigation scheme, farmers adopted Bt maize but did not comply with resistance management practices. The findings underscore the urgent need for farmer education on insect biology, responsible pesticide use, and proper implementation of Bt maize. The study also highlights the importance of collective rather than individual efforts in managing *S. frugiperda*, as the consequences of mismanagement can affect all farmers. These findings reveal major gaps in Integrated Pest Management (IPM) practices among smallholder farmers in Limpopo province, South Africa.

1. Introduction

Maize (*Zea mays*) is one of the main staple crops to over 300 million people in Africa (Santpoort, 2020). Smallholder farmers are the main maize producer in Sub-Saharan Africa. They produce maize on approximately 40 million ha of land (FAOSTAT, 2021). Smallholder farmers utilize maize in various ways. Green maize is harvested, sold and eaten roasted or boiled, whereas dry milling of maize grain may produce maize mealie, maize flour, corn oil, pop corns and other industrial uses such as alcoholic beverages (Ekpa et al., 2019). Various abiotic stresses (such as poor soil fertility and drought) (Salika and Riffat, 2021), socio-economic constraints (including lack of access to new technologies such as improved seed cultivars), poor infrastructures, and high cost of fertilizers and pesticides (Chimonyo et al., 2020) limit maize production. Further, biotic stresses, including weeds (e.g. *Striga*) (Parker, 2012), pathogens (e.g. gray leaf spot, downy mildew and maize

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lethal necrosis), and insect pests (e.g. the maize stalkborers *Busseola fusca* and *Chilo partellus* (Hardwick et al., 2019) and the recent arrival in Sub-Saharan Africa, *Spodoptera frugiperda*) (Matova et al., 2020), are an additional threat to maize production.

Spodoptera frugiperda, also known as the fall armyworm (FAW) is native to eastern and central north America (Sparks, 1979) and was first confirmed in South Africa in 2017 (FAO, 2019). *Spodoptera frugiperda* has a holometabolous life cycle which includes egg, six larval instars, pupal and adult stages. *Spodoptera frugiperda* larvae are responsible for damage of more than 353 host plants from 76 different families which include Poaceae, Fabaceae, Solanaceae, Asteraceae and Rosaceae (Montezano et al., 2018). While cereals such as wheat, sorghum and maize are the main host of *S. frugiperda*, its preference is maize (Day et al., 2017). *Spodoptera frugiperda* larvae feed on both vegetative (developing leaves, stem, and whorl) and reproductive (tassel, ear, kernel and silk) parts of the maize plant (Pannuti et al., 2015). The feeding of *S. frugiperda* on maize results in reduced yield losses. Yield losses due to *S. frugiperda* reduce household income and threatens food security, especially for smallholder farmers in African communities (Bannor et al., 2022). This is attributed to increased cost of production due to increased labour and pesticide costs for controlling *S. frugiperda* thus posing challenges for sustainability.

Although studies have indicated that effective control of any insect pest requires Integrated Pest Management (IPM) (Stenberg, 2017; Dara, 2019), it is not applicable to all farmers due to variations in their socio-economic conditions (Houngbo et al., 2020). Control of insect pests requires correct identification of the pest and financial resources to purchase pesticides, traps and improved seeds, that most smallholder farmers in rural communities cannot afford (Day et al., 2017). Understanding smallholder farmers' knowledge (what they know about the biology, ecology and behaviour), perception (how farmers perceive *S. frugiperda* infestations, damage caused by this pest and the effectiveness of the management practices they have adopted) and practice (what they currently do), as well as their challenges in controlling pests are important for the development of research designed for sustainable integrated management. For example, understanding smallholder farmers' perceptions about biological control can provide insight into their motivation to apply or not apply pest management methods that use natural enemies (Wyckhuys et al., 2018). Similarly, understanding smallholder farmers' perception on Bt maize technology may provide answers on its adoption as well as compliance to those already planting Bt maize (Mushunje et al., 2011). It is also important to understand farmers' indigenous knowledge and strategies they use to control insect pests. Such information is useful for researchers in designing IPM strategies that can meet their needs. However, information regarding smallholder farmers' perception, knowledge and management of *S. frugiperda* is limited and varies among maize producers.

Emerging evidence suggests that *S. frugiperda* knowledge and management practices vary among farmers in Zimbabwe (Baudron et al., 2019), Ethiopia, Kenya (Kumela et al., 2019), Zambia (Kansiime et al., 2019), Malawi (Murray et al., 2019), Mozambique (Caniço et al., 2021), Ghana (Asare-Nuamah, 2022), Bangladesh (Ullah et al., 2023), South Asian countries: Pakistan, India, Sri Lanka and Napal (Khan et al., 2023), Benin (Houngbo et al., 2024) and Uganda (Odong et al., 2024). However, such studies are lacking in South Africa.

This research explored smallholder farmers' perceptions, knowledge, and management practices for *Spodoptera frugiperda* in the Thulamela Local Municipality irrigation schemes of Limpopo Province, South Africa. The study was conducted using focus group discussions, including farmers from groups of different gender and age classes. Discussions assessed knowledge of the identification of *S. frugiperda*, management practices, source, frequency and efficacy of insecticides, and the use and compliance of Bt maize. Results from this study will assist to inform sustainable pest management strategies in this region.

2. Methodology

2.1. Description of the study area

The study was conducted at the Dzindi and the Tshiombo irrigation schemes in the Thulamela Local Municipality, Vhembe district, Limpopo province of South Africa. The two schemes are about 45 km apart.

The Dzindi (23°01′S; 30°26′E) is an irrigation scheme which was constructed in 1954 (see Fig. 1A).

The scheme is situated 6 km south-west of Thohoyanḓou, a main town in Vhembe District. The production area is divided into four separate blocks subdivided into 106 plots of approximately 1.28 ha each. There are 25 plots in Block 1, 35 in Block 2, 13 in Block 3 and 33 in Block 4. Farmers plant maize with vegetables throughout the year.

The Tshiombo irrigation scheme (S 22°47.863; E30°27.194) was constructed between 1959 and 1964 (see Fig. 1B.). It is situated 45 km north-east of Thohoyanḓou. The scheme covers seven villages in which the smallholders live: Maṱangari, Tshiombo, Maraxwe, Mianzwi, Matombotswuka, Mbahela and Mutshenzheni. The scheme is subdivided into 1041 plots, each about 1.2 ha in size. Farmers maintain a continuous cycle of maize cultivation throughout the year, leading to plots with maize at different growth stages alongside intercropped or rotated crops, predominantly including sweet potatoes, groundnuts, sugar beans, and vegetables such as cabbage, nightshade, and spinach.

2.2. Study design

The study employed a mixed-methods approach. The qualitative approach was used to investigate smallholder farmers' knowledge, perceptions, and management practices of *S. frugiperda*, enabling in-depth engagement and insight into their experiences. The quantitative analysis allowed for measurement and description of findings. Participants were selected using criterion-based purposive sampling, targeting smallholder farmers cultivating less than 2 ha and located in areas with officially reported cases of *S. frugiperda*. The presence of the pest was also confirmed by the researcher during field insect collections. The study included diverse participants across age and gender to capture varying farming experiences.

Consultation with traditional leaders (*vhakoma* through *vhamusanda*) and agricultural extension officers ensured approval and ethical compliance. Consent documents were obtained during site visits. Extension officers played a key role in organizing participants, with communication managed via WhatsApp for smartphone users and through extension officers and farmer committee leaders for others.

2.3. Data collection

Data was collected via focus group discussions, also referred to as focus interviews, intensive interviews, unstructured conversational interviews, or ethnographic interviews (Parker and Tritter, 2006). This method was selected because it assists in obtaining comprehensive information which includes reasons behind the answers, opinions or emotions expressed.

2.3.1. Focus group discussion procedure

A series of 16 focus group discussions were organized and conducted around the two Thulamela Local Municipality irrigation schemes from 28 June to July 6, 2022. Of these, twelve discussions took place at the Dzindi irrigation scheme, while four were held at the Tshiombo irrigation scheme. Most participants from the Dzindi irrigation scheme confirmed their participation, and as the first site visited, the focus group discussions were successfully conducted there. In contrast, participation at Tshiombo irrigation scheme was lower, and due to time constraints, only four group discussions were engaged at that site. Each participant was assigned a unique identifier, which allowed for the recording and analysis of individual responses where applicable. Each

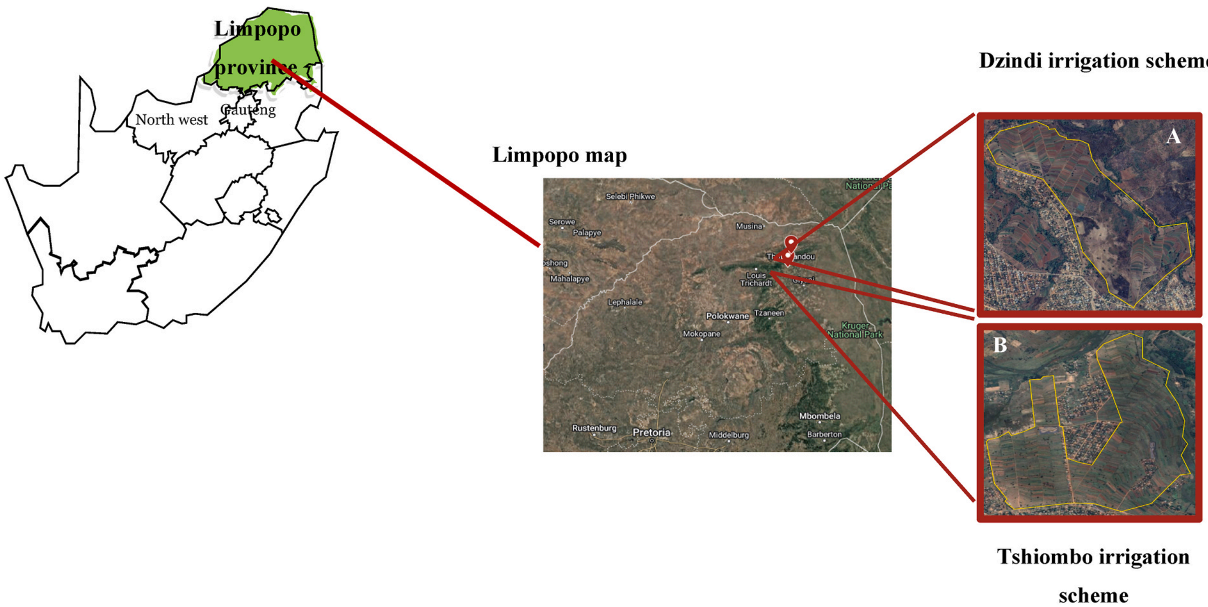

Fig. 1. A). The Dzindi and the B).Tshiombo irrigation scheme map.

focus group discussion was tailored to include diverse participant groups (see Table 1.).

2.3.2. Moderator and assistant roles

The researcher (moderator) conducted focus group discussions with the support of two qualified assistants specializing in social sciences within the study region. Before the discussions, the assistants were briefed on the study's objectives to ensure alignment with its goals. Their involvement in the planning process allowed them to contribute ideas for improving discussion flow. Importantly, both the researcher and assistants shared a common cultural background with participants, enhancing trust, rapport, and understanding during the discussions.

Table 1
Number of groups of participants and their composition.

Group number	Location	Age group	Male	Female	Group composition	Total
1	Dzindi	>60	8	0	Males	8
2	Dzindi	36 to 60	4	2	Mixed	6
3	Dzindi	≤35	0	8	Females	8
4	Dzindi	≤35	2	5	Youth (mixed)	7
5	Dzindi	≤35	0	11	Females	11
6	Dzindi	>60	8	0	Males	8
7	Dzindi	>60	0	7	Females	7
8	Dzindi	36 to 60	0	6	Females	6
9	Dzindi	≤35	3	3	Youth (mixed)	6
10	Dzindi	>60	5	2	Mixed	7
11	Dzindi	≤35	6	3	Mixed	9
12	Dzindi	36 to 60	4	2	Mixed	6
13	Tshiombo	>60	7	0	Males	7
14	Tshiombo	>60	0	10	Females	10
15	Tshiombo	≤35	2	4	Youth (mixed)	6
16	Tshiombo	36 to 60	3	3	Mixed	6
Total			**52**	**66**		**118**

"Mixed)" refers to groups that included both males and females, with participants categorized by age into three groups: under 35 years, 30–60 years, and over 60 years. "Youth (mixed)" indicates that the group consisted of both male and female youth participants.

2.3.3. Focus group discussion format and tools

The study adhered to COVID-19 safety regulations, providing sanitizers and masks. Seating was arranged in a circle to encourage discussion. The facilitator welcomed participants, obtained consent for recordings, photos, and videos, and used a Zoom® H1n-VP handy recorder for audio documentation. The moderator, introduced the two assistants and their roles, outlined the research objectives, set the discussion ground rules, and distributed key documents, including a printed socioeconomic questionnaire, a focus group confirmation letter, a consent form, and a letter of gratitude. Confidentiality was assured, with all responses anonymized for research purposes.

2.3.4. Focus group discussion topics

To explore farmers' perception, knowledge, and management practices regarding *Spodoptera frugiperda*, focus group discussions were conducted. Participants were encouraged to express their views freely, with the reassurance that there were no wrong answers. The discussions were guided by topic outlines (see Appendix A) and facilitated using open-ended probes.

The discussion began with the researchers informing the farmers that the session would focus on *S. frugiperda*, commonly known among them as *luvhungu lwa mavhele* (maize worm), in order to use terminology familiar to the participants and encourage open dialogue. Once the term *luvhungu lwa mavhele* was mentioned, farmers immediately responded with concern, saying things like *"Eish, this one is a problem"*, which opened the floor for deeper discussion. The researcher then posed a follow-up question to elicit deeper insights, asking farmers to explain the nature of the problem posed by *S. frugiperda*. This prompted participants to share their lived experiences, which provided valuable data on their perception of the pest's impact on maize production.

Photographs showing the egg, larval, pupal, and adult (moth) stages of *S. frugiperda* (see Appendix A) were presented to farmers to assess their ability to recognize and accurately identify each stage of the pest's life cycle. Individual responses were recorded to assess their knowledge and recognition of the pest's developmental stages. The assumption was that if farmers could correctly identify all different *S. frugiperda* life stages then it means that they understand its biology. All the names and terms used by farmers to describe the stages were recorded. Since *S. frugiperda* was already widely known as *luvhungu lwa mavhele*, the researcher further inquired whether there were any other local names used. These alternative local names use by the farmers in the area were also documented.

To evaluate whether farmers could correctly identify the damage caused by *S. frugiperda* and distinguish it from damage caused by other lepidopteran pests, they were shown images of maize plants with visible symptoms. These included damage from *S. frugiperda* and other common lepidopteran pests (see Appendix A). Farmers were asked what they thought caused the damage. Their responses were used to evaluate their ability to identify the pest and understand its associated damage symptoms.

Following the farmers' responses regarding the damage symptoms, the researchers sought to understand their pest management practices. Farmers were asked to describe the actions they take upon observing such damage on their crops. Since chemical control was the most mentioned strategy, farmers were asked to list the insecticides by writing them down in a provided piece of paper and they were told not to be concerned about the spelling accuracy in order not to limit their writing. Participants were asked to indicate, for each insecticide listed, whether they perceived it as effective in controlling *S. frugiperda*, as well as the frequency and timing of its application. The names were verified by an extension officer, and the insecticides were categorized according to their active ingredients and chemical groups. Additionally, farmers who had adopted Bt maize were identified, and their perceptions of its effectiveness against *S. frugiperda* were recorded. For the Dzindi irrigation scheme farmers who had adopted Bt maize, questions were asked to assess their understanding of the refuge bag (non-Bt seed maize included in the Bt maize bag). This aimed to evaluate their knowledge of resistance management practices associated with Bt maize.

A the end of the session, the facilitator asked the participants to offer their opinions and reflect on the discussion. The same set of topics were used at all focus group discussions to ensure consistency across different groups. Each session was aimed to last for about 1 h 30 min.

2.4. Data analysis

Focus group discussions were transcribed and translated from Tshivenḓa to English. Data were analysed using the thematic analysis approach described by Braun and Clarke (2006). The process included several key steps as outlined below in Appendix B. The researcher familiarised themselves with the data through repeated reading of the transcripts. Initial codes were generated by systematically coding meaningful segments of text. Codes with similar meanings were then organised into broader categories, which were further grouped into sub-themes. The sub-themes and original transcripts were revisited to ensure that the identified themes accurately represented the participants' responses. Finally, the sub-themes were refined and consolidated into main themes, which were clearly defined and named (see Appendix C). Variables were summarized using frequencies and percentages, particularly for demographic characteristics and responses related farmers knowledge, perception and management practices of *S. frugiperda*. Coded data were exported to Microsoft Excel. Frequency counts or percentage for each theme were calculated and subsequently imported into SPSS Statistics for Windows, Version 25.0 for descriptive analysis (IBM Corp, 2017). To ensure participant anonymity, all identifying information was removed and replaced with pseudonyms, which were used in the reporting of direct quotations.

3. Results

3.1. Demographic information of smallholder farmers who participated in the focus group discussion

The socio-economic features of the smallholder farmers in the two study sites are provided in Table 2.

The participants were divided into three age groups. The age distribution shows that most participants were either 35 years or younger (40 %) or older than 60 years (40 %), while only 20 % were between the ages of 36 and 60. Regarding education, the majority of participants had attained a high school education (47.46 %), while the minority (13.56 %) had achieved tertiary education. A proportion had either no formal education (24.58 %) or only completed primary school (14.41 %). The gender distribution shows a slightly higher number of female participants (55.93 %). Farming experience is varied, with the majority of participants having more than 30 years of experience (27.83 %), followed by those with 11–20 years (23.48 %) and 21–30 years (24.35 %), indicating that many individuals have been engaged in farming for much of their lives. The smaller proportions of participants with less than 5 years (12.17 %) and 6–10 years (12.17 %) of experience may represent younger generations or those new in agriculture (Table 2).

Table 2
Demographic information of smallholder farmers who participated in the focus group discussion.

Variables	Frequency	Percentage
Age group (years)		
≤35	47	39.83
36 to 60	24	20.34
More than 60	47	39.83
Education level		
None	29	24.58
Primary	17	14.41
High school	56	47.46
Tertiary	16	13.55
Gender		
Female	66	55.93
Male	52	44.07
Farming experience (years)		
Less than 5	14	11.86
6–10	15	12.71
11–20	28	23.73
21–30	29	24.58
More than 30	32	27.12
Total	**118**	**100**

3.2. Farmers' perceptions of Spodoptera frugiperda invasion at the Thulamela Local Municipality irrigation schemes

Since the 2016/2017 season to date, farmers consistently reported encountering *S. frugiperda* damage on maize throughout both vegetative and reproductive stages. All participants (100 %) perceived it as the most destructive insect pest affecting maize production in the region (see Table 3).

Approximately 24 % of the farmers believed that infestations typically coincide with the onset of rainfall. A minority (11 %) of respondents from both sites indicated that *S. frugiperda* was not a major concern when pesticide mixtures ("cocktails") were used. Additionally, 11 % of farmers reported that they had not encountered *S. frugiperda* in the past when cultivating a local maize landrace known as *Tshikundanwedzhi* (see Table 3). However, this variety is no longer in use, having been replaced by improved maize cultivars. As Nyawasedza [1] puts it: "*Luvhungu lwo ḓisiwa nga makhuwa musi vha tshi ri ḓisela mbeu dzavho hedzi dzo no tea u rengiwa tshifhinga tshoṱhe, riṋe ri tshi lima Tshikundanwedzhi fhedzi ro vha ri sina luvhungu*".

Translation: "*Spodoptera frugiperda* was brought by white people with their improved cultivars so that we can repurchase the seeds unlike in the past when we used to plant Tshikundanwedzhi that was not susceptible to any insect pest."

3.3. Identification of Spodoptera frugiperda life stages by smallholder farmers

When farmers were shown picture of *S. frugiperda* eggs, larva, pupa and adult moth, they were asked to describe or name what they saw.

Eggs: Of the farmers who were surveyed, the vast majority, approximately 87 %, did not identify spider webs as *S. frugiperda* eggs,

Table 3
Farmers' perception of *S. frugiperda*.

Perception	Dzindi Males (N = 10) Frequency (%)	Dzindi Females (N = 12) Frequency (%)	Tshiombo Males (N = 6) Frequency (%)	Tshiombo Females (N = 9) Frequency (%)	Total (N = 37) Frequency (%)
Most destructive	10 (100 %)	12 (100 %)	6 (100 %)	9 (100 %)	37 (100 %)
Arrive with rainfall	2 (20 %)	3 (25 %)	2 (33 %)	2 (22 %)	9 (24 %)
Not a problem if we mix pesticides (cocktails)	1 (10 %)	1 (8 %)	1 (17 %)	1 (11 %)	4 (11 %)
Never experienced it when planting *Tshikundanwedzhi*	0 (0 %)	4 (33 %)	0 (0 %)	0 (0 %)	4 (11 %)

while approximately 13 % incorrectly identified them as such. The majority of farmers (86 %) identified *S. frugiperda* eggs as sugar. Moreover, approximately 77 % of farmers linked frass with these eggs, while 14 % identified them as bird droppings (Table 4). A small proportion of farmers (11 %) perceived the eggs as spider webs, while 14 % mistakenly identified them as bird droppings (Table 4).

Larvae: All survey farmers were able to identify *S. frugiperda* at its larval stage by describing its feeding habits and frass as an indication of *S. frugiperda* presence on their crops. Farmers at the Dzindi irrigation scheme were in agreement with a female farmer who indicated that *S. frugiperda* has two heads.

Nkhangweni[2]: *"Luvhungu lu na ṱhoho mbili, lu ḽa mavhele lwo ṱoka ṱhoho nthihi fhasi ngeno inwe yo sedza nṱha, lu tshi ḓi dzumba nga malaṱwa alwo"*.

Translation: "When *S. frugiperda* larvae are feeding with one head facing down, the other head is tasked with covering the body with frass."

All farmers (100 %) commonly referred to the larval stage of *S. frugiperda* as "Luvhungu" or "Tshivhungu" which are general Tshivenḓa terms for worms (Table 5). Other local names included "Tshibagarasi," used by 11 % of farmers, and "Tshirende" (11 %). Additionally, some farmers adopted Shona names from their Shona-speaking workers. Specifically, 11 % of farmers used "Tshibagarasi," while 23 % referred to *S. frugiperda* as "Makonya" (Table 5).

Pupae: Farmers at the Thulamela Local Municipality irrigation schemes reported not having seen pupae on maize. Farmers reported sporadically encountering pupae while walking on gravel roads or among the bushes. All farmers (100 %) commonly refer to pupae as "Sumbandila," (see Table 5) meaning "lead the way," which serves as the local term used for any pupae. Farmers do not associate pupae with *S. frugiperda* or any other insect. Instead, they hold the belief that pupae aid them in finding direction when lost or guiding them to locate lost livestock. According to their belief, upon touching a pupa, it responds by wriggling and then settles with its cremaster pointing towards the right direction.

Table 4
Farmer's perception of *S. frugiperda* eggs.

Perception	Response	Frequency	Percentage
Spider webs	No	103	87.29
	Yes	15	12.71
Sugar	No	17	14.41
	Yes	101	85.59
Frass	No	27	22.88
	Yes	91	77.12
Bird droppings	No	102	86.44
	Yes	16	13.56

3.4. *Spodoptera frugiperda management practices by smallholder farmers*

Chemical control by use of insecticides was reported as the main control of *S. frugiperda* by all farmers. According to the majority of farmers, insecticides are modern ways of controlling insect pests.

Tshishonga [3]: *"Ri shumisa mishonga, ndi nnyi ane a do fara mafola nga tshimanzhe-manzhe?"*

Translation: "We only use chemicals to control *S. frugiperda* as it is the modern way of controlling insects, who will use nicotine leaves to control insects in modern days?"

During the study period, all farmers at the Dzindi irrigation scheme had adopted Bt maize as a strategy to manage *Spodoptera frugiperda*. This decision was largely influenced by training they reported receiving from the seed company, which also facilitated access to the seeds, allowing farmers to purchase them in bulk at a reduced price. However, despite adopting Bt maize, farmers continued to use insecticides on the refuge areas. Whenever they observed *S. frugiperda* feeding on the refuge plants, they applied chemical treatments to control the pest.

3.4.1. *Source of insecticides by smallholder farmers*

All smallholder farmers receive insecticides once a year as part of a government subsidy. Farmers reported that they receive insecticides such as include Methomyl 200 SL (WHO class IA), Methomex ®900 SP (WHO class IB), Tamron 505 SL MSDS (WHO class IB), Masta 900 SP (WHO class IB), Avi gard (WHO class IB), while they purchase some from local certified retailers. Some of the insecticides used by the farmers to control *S. frugiperda* are listed in Table 6.

3.4.2. *Frequency of insecticide application on maize*

Farmers reported applying insecticides as a preventative measure against *S. frugiperda*, often before observing any damage symptoms. A male farmer reported applying insecticides on soil immediately after ploughing, once noticing white web-like substances on the soil. Most farmers (92 %) stated that they apply insecticides weekly, 81 % begin applications at the two-leaf stage of maize, and 3 % apply even before planting (Table 7).

Farmers who plant Bt maize also apply insecticides weekly to the refuge areas, for those who include refuge plantings in their fields. Farmers cease application once maize growth reaches the reproductive stage (tassel formation) due to the inability of knapsacks to reach the reproductive stage of maize.

3.4.3. *Effectiveness of insecticides used by smallholder famers against S. frugiperda*

All farmers assessed the effectiveness of the insecticides listed in Table 7 based on personal experience. These insecticides included products distributed annually through a government subsidy program, which all participants received and used for managing *S. frugiperda*. In addition, farmers were initially asked to list any other insecticides they had used for this purpose (as shown in Table 6). A consolidated list combining both sources was compiled and returned to the participants, who were then asked to indicate whether each insecticide was effective or not. As all insecticides included in the final list had been used by the farmers, the effectiveness ratings reflect direct, firsthand experience. The majority of farmers perceived individual insecticides such as Adama

Table 5
Local names for *S. frugiperda* life stages used by smallholder farmers.

Local name	Dzindi Males (N = 10) Frequency (%)	Dzindi Females (N = 12) Frequency (%)	Tshiombo Males (N = 6) Frequency (%)	Tshiombo Females (N = 9) Frequency (%)	Total (N = 37) Frequency (%)
Larva					
Luvhungu	10 (100 %)	12 (100 %)	6 (100 %)	9 (100 %)	37 (100 %)
Tshivhungu	10 (100 %)	12 (100 %)	6 (100 %)	9 (100 %)	37 (100 %)
Mbungu	2 (20 %)	7 (58 %)	3 (50 %)	2 (22 %)	14 (38 %)
Tshirende	1 (10 %)	2 (17 %)	0 (0 %)	1 (11 %)	4 (11 %)
Tshibagarasi	0 (0 %)	2 (17 %)	1 (17 %)	1 (11 %)	4 (11 %)
Makonya	1 (10 %)	0 (0 %)	6 (100 %)	1 (11 %)	8 (23 %)
Pupae					
Sumbandila	10 (100 %)	12 (100 %)	6 (100 %)	9 (100 %)	37 (100 %)
Adult moth					
Tshisusu	10 (100 %)	12 (100 %)	6 (100 %)	9 (100 %)	37 (100 %)

Table 6
Types of insecticides used by smallholder farmers from the Dzindi and Tshiombo.

Trade Name	Active Ingredient	Chemical Group	WHO Hazard Class	IRAC MoA Group
Adama Abamectin	Abamectin	Avermectin	II	6
Allice 222 SL	Acetamiprid	Neonicotinoid	II	4A
Avi Gard	Mercaptothion	Organophosphate	IB	1B
Cartap	Cartap hydrochloride	Nereistoxin analog	II	14
Cypermethrin 200 EC	Cypermethrin	Pyrethroid	II	3A
Hunter® 24 SC	Chlorfenapyr	Pyrrole	II	13
Kemprin 200 EC	Cypermethrin	Pyrethroid	II	3A
Kombat Malathion	Malathion	Organophosphate	III	1B
Makhro Cyper	Cypermethrin	Pyrethroid	II	3A
Malasol	Mercaptothion	Organophosphate	IB	1B
MECTI	Abamectin	Avermectin	II	6
Methomex® 900	Methomyl	Carbamate	IA	1A
Methomyl 200 SL	Methomyl	Carbamate	IA	1A
Phosdrin® 500 SL	Mevinphos	Organophosphate	IB	1B
Stalkborer Granules	Carbaryl	Carbamate	II	1A
Steward® 150 EC	Indoxacarb	Oxadiazine	II	22A
Supermetrin	Cypermethrin	Pyrethroid	II	3A
Tamron 585 SL	Methamidophos	Organophosphate	IB	1B
Warlock® 19.2 EC	Emamectin benzoate	Avermectin	II	6

Notes: WHO Hazard Class; Based on the World Health Organization classification of pesticides by hazard (2019). Class IA; Extremely hazardous, IB; Highly hazardous, II; Moderately hazardous, III; Slightly hazardous. IRAC MoA Group; Classification based on the Insecticide Resistance Action Committee mode of action. IRAC Group 1A; Carbamates, 1B; Organophosphates, 3A; Pyrethroids, 4A; Neonicotinoids, 6; Avermectins, 13; Uncouplers of oxidative phosphorylation, 14; Nereistoxin analogues, 22A.

abamectin, Allice 222 SL, Avi guard, Cartap, Cypermethrin 200 EC, Hunter 24SC, Kemprin 200 EC, Kombat Malathion, Makhro cyper, Malasol, MECTI, Stalkborer granules, Steward ®150 EC, Supermetrin, and Tamron 585 SL to be 100 % effective (see Table 8).

The majority (81 %), of participants conveyed that Methomex had lost its efficacy, whereas Methomyl 200 SL was deemed ineffective by 91 % of respondents. Phosdrin ®500 SL, on the other hand, was perceived as effective by 82 % of the respondents, with 18 % expressing its ineffectiveness (Table 8).

Farmers at the Dzindi and the Tshiombo irrigation scheme find insecticide cocktails more effective in controlling *S. frugiperda*; they mix Ampbligo, Adama and Methomex. One male farmer from the Dzindi irrigation scheme mixes any insecticides (even for other lepidopterans) he has in his storage as a preventative measure against *S. frugiperda*. Other cocktails mixed to control *S. frugiperda* by farmers includes

Table 7
Frequency of insecticides application.

Frequency of application	Response	Frequency	Percentage
Before planting	No	115	97.46
	Yes	3	2.54
Weekly	No	10	8.47
	Yes	108	91.53
When maize is at two leaf stage	No	23	19.49
	Yes	95	80.51

Table 8
Famers' perception of insecticide effectiveness: comparison between individual insecticides and insecticide cocktails.

Insecticide	Frequency (Yes)	Frequency (No)	Percentage (Yes)	Percentage (No)
Adama Abamectin	118	0	100	0
Allice 222 SL	118	0	100	0
Avi Gard	118	0	100	0
Cartap	118	0	100	0
Cypermethrin 200 EC	118	0	100	0
Hunter® 24 SC	118	0	100	0
Kemprin 200 EC	118	0	100	0
Kombat Malathion	118	0	100	0
Makhro Cyper	118	0	100	0
Malasol	118	0	100	0
MECTI	118	0	100	0
Methomex® 900	23	95	19.49	80.51
Methomyl 200 SL	11	107	9.32	90.68
Phosdrin® 500 SL	97	21	82.2	17.8
Stalkborer Granules	118	0	100	0
Steward® 150 EC	118	0	100	0
Supermetrin	118	0	100	0
Tamron 585 SL	118	0	100	0
Warlock® 19.2 EC	118	0	100	0
Insecticide cocktails	102	16	86.44	13.56

Melasol, Allice 222 SL and Cartap and Allice 222 SL, Cartap and Methomex ®900. When asked about their knowledge of mixing insecticide cocktails, some farmers cited learning from their parents' practices, while others mentioned experimenting with mixing as part of their efforts to develop effective strategies for pest control.

Alfred[4]: "*Ri vha ri khou zama plane uri Luvhungu lu fe.*"

Translation: "We are trying our luck to kill *S. frugiperda*. "

3.4.4. The use of Bt maize by smallholder farmers

In the current study, there is a notable difference in farmers' knowledge of Bt maize. Throughout the survey period, farmers in the Tshiombo irrigation scheme were found to lack access to information about Bt maize technology. In contrast, farmers in the Dzindi irrigation scheme have enthusiastically embraced Bt maize technology after receiving training from a seed company, coupled with practical demonstrations in trial plots.

During the period of survey, all farmers perceive Bt maize as effective in controlling *S. frugiperda*.

These farmers cite several reasons for preferring Bt maize seeds, including increased yield due to larger grains, reduced reliance on insecticides for controlling *S. frugiperda*, and the elimination of the need to hire labour for weeding, as Bt maize allows them to use herbicides instead.

Rashaka[5]: "*Mbeu hei i sa ḽiwi i a ri thusa ngauri a ri tsha hwala tshigubu tsha mushonga.*"

Translation: "Bt maize varieties are important to us because we no longer carry knapsack with insecticides to control *S. frugiperda*".

Farmers source their seeds from commercial seed companies and their vendors through their contact person assigned by the company. The most preferred cultivar due to a bigger size grain. The majority of farmers did not know the difference between Bt (BR) and Roundup ready (R) maize cultivars. As a result, farmers refer to all these cultivars as Roundup.

3.4.5. Bt compliance by smallholder farmers

None of the farmers who have adopted Bt maize were compliant with Bt regulations, resulting in significant discrepancies. When questioned about the refuge, specifically their awareness of it and the obligations concerning planting a non-Bt maize refuge adjacent to their Bt maize fields, farmers provided widely varying responses. Some farmers perceived the non-Bt maize refuge as a complimentary incentive or a bonus for buying the seeds.

Thiofhi[6]: "*Heiḽa phakhethe yo no rengisiwa na mavhele a sa ḽiwi ndi basela.*"

Translation: "Refuge maize is a free token (a complimentary gift after purchasing Bt maize)".

Farmers who had undergone training in Bt maize technology likened the refuge to a protective barrier, designed to safeguard Bt maize crops from damage by *S. frugiperda*. Despite this, none of the surveyed farmers followed proper protocols for planting the refuge maize. Practices were inconsistent—some planted the non-Bt maize at their homes while cultivating Bt maize in their fields, others planted a refuge only if they had leftover space after planting Bt maize, and some intercropped the two varieties. Additionally, some farmers recycled Bt maize seeds, a traditional practice for selecting superior cultivars for the following season. They were skeptical of seed companies, suspecting the insistence on purchasing seeds annually was profit-driven, believing that recycled Bt maize would provide similar insecticidal protection against *S. frugiperda*.

3.4.6. Other sustainable management practices of S. frugiperda by smallholder farmers

When farmers were provided with an opportunity to mention some of the indigenous/traditional ways of controlling *S. frugiperda* they mentioned practices that they used in the past to control other insects, but they have not tried them on *S. frugiperda*. These practices include intercropping sugarcane with maize, morning sprinkling of nicotine aqueous solution (soaked overnight), and aqueous solution of the Lemon bush (*Lippia javanica*), known as *Musudzungwane*. However, farmers are reluctant to try these methods on *S. frugiperda,* because they believe they were used in the 'olden days' and were replaced by insecticides.

4. Discussion

This study provided insights on the Dzindi and the Tshiombo irrigation scheme farmers perception and knowledge about *S. frugiperda* (identification, its biology or life stages), as well as the way they manage this insect pest on maize. The participants were divided into three age groups, revealing an interesting pattern in the age distribution. A substantial portion of the participants fell into either the youngest group, aged 35 years or younger, or the oldest group, aged above 60. This suggests that farming continues to attract both the youth—possibly due to increasing interest in agriculture or lack of alternative employment—and older individuals who have likely being farming for much of their lives. In contrast, the smaller number of participants aged between 36 and 60 may suggest that people in this age group are more likely to look for work outside of farming, possibly because they have better chances of finding jobs in other fields or have moved to towns and cities. In contrast, the smaller number of participants aged between 36 and 60 may suggest that people in this age group are more likely to look for work outside of farming, possibly because they have better chances of finding jobs in other fields or have moved to towns and cities. This distribution provides useful insight into generational engagement in farming and potential areas of focus for agricultural support and intervention programs.

The results indicated that all surveyed farmers perceived *S. frugiperda* as the most devastating insect pest of maize. *Spodoptera frugiperda* is considered a new and destructive pest by many farmers across Africa. Its sudden emergence and the extent of damage it causes have caught farmers off guard, as reported in Mozambique (Houngbo et al., 2020) and Benin (Caniço et al., 2021). It is widely regarded as a major challenge during the cropping season in Zambia (Kansiime et al., 2019). Farmers in Ghana associated *S. frugiperda* with "witchcraft", the works of their enemies, anger of the gods and bad luck on their government (Asare-Nuamah, 2022). In contrast, some Ugandan farmers view *S. frugiperda* as a manageable pest rather than a threat to maize production, as they believe that it is possible to eradicate it if farmers have effective and correct insecticides (Kalyebi et al., 2023). Variations in farmers' perceptions of *S. frugiperda* across regions may result from differences in infestation levels, prior experience with the pest, and the effectiveness of control measures (Asare-Nuamah, 2022). Farmers facing frequent infestations or lacking effective support are more likely to perceive the pest as a serious threat, while those with access to effective and sustainable control strategies may view it as less problematic.

Farmers at the Dzindi and the Tshiombo irrigation scheme reported that they occasionally dissect maize whorls to identify the insect responsible for the observed damage, which has contributed to their familiarity with the larval stage of *S. frugiperda*. The majority of farmers in Zambia (91 %) were able to identify the larval stage of *S. frugiperda* (Kansiime et al., 2019). Similarly, farmers in Ethiopia and Kenya (Kumela et al., 2019) and Ghana (Koffi et al., 2020) were able to correctly identify *S. frugiperda* from the larval stage. In contrast, farmers and extension officers in Mozambique confuse *S. frugiperda* with other lepidopteran pests such as stemborers (Caniço et al., 2021).

The Dzindi and the Tshiombo, farmers' inability to identify all life stages limits their ability to apply timely and appropriate control measures. Gaining insight into the biology and behaviour of *S. frugiperda* is essential for successful pest control, as it enables farmers to apply control measures at the stages when the pest is most susceptible (Murray et al., 2019). Early detection at the egg stage is important, as it allows control before the larvae move into the maize whorl and cause significant damage. In regions where farmers can correctly identify the eggs, they often crush them (Tambo et al., 2020). Accurate identification of the adult moths is also important when using pheromone traps, as misidentification can lead to incorrect estimates of infestation levels. For instance, traps can attract other noctuid species, complicating monitoring efforts (Saveer et al., 2023). Therefore, failure to recognize each life stage of *S. frugiperda* reduces the effectiveness of monitoring and control, increasing the risk of crop damage. In addition, It is also important for extension workers to be familiar with the local names farmers use for *S. frugiperda*, as this facilitates clearer communication and more effective knowledge transfer. Employing terminology familiar to farmers enhances their understanding of the information being conveyed, making it easier for them to apply the recommended pest management practices effectively (FAO and CABI, 2019).

Smallholder farmers at the Dzindi and Tshiombo irrigation schemes exhibited limited pest monitoring and scouting skills, as their discussions revealed no awareness of traps or standardized sampling techniques for insect surveillance and management. In contrast, smallholder farmers in Cameroon begin monitoring their maize fields four to five days after planting to assess damage symptoms and the presence of frass on the stems, which serve as positive indicators of *S. frugiperda* infestation (Akeme et al., 2021). Farmers in Rwanda, who received support from the Food and Agricultural Organization (FAO), were equipped with smart cell phones installed with the Fall Armyworm Monitoring and Early Warning System (FAMEWS) and sex pheromone lures with bucket traps, allowing them to detect *S. frugiperda* early (FAO and CABI, 2019). The lack of such monitoring tools among farmers at the Dzindi and the Tshiombo irrigation schemes can be attributed to limited access to technology, training, and skills necessary for effective scouting.

All sampled farmers from the Dzindi and the Tshiombo irrigation schemes relied on insecticides as the main control for *S. frugiperda*. This is consistent with other smallholder farmers in African countries such as Zimbabwe (Baudron et al., 2019), Kenya and Ethiopia (Kumela et al., 2019), Malawi (Murray et al., 2019), Mozambique (Caniço et al., 2021), Ghana (Asare-Nuamah, 2022) and Botswana (Makale et al., 2022). This reliance of insecticides by farmers may be due to the fact that the response of many African governments to *S. frugiperda* invasion was the immediate registration followed by farmers subsidy of pesticides for its control (Day et al., 2017). For instance, the South African government registered about 50 insecticides in response to *S. frugiperda* invasion and annually subsidize smallholder farmers with some of these insecticides (DAFF, 2017). This is consistent with the government in Ghana, which supplied smallholder farmers with pesticides as part of a planting for food and job initiative (Asare-Nuamah, 2022). Rwanda deployed their army in order to halt the spread of *S. frugiperda* through distribution of pesticides and hand-picking of larvae on farmer's fields (Rukundo et al., 2020). Of great concern is that the farmers at irrigation schemes use insecticides that are highly toxic (falls under category WHO IA, IB and II), among which is Tamron banned by the United States in 2009 (U.S. EPA, 2002) and also banned in Zimbabwe, due to its high toxicity to non-target organisms including humans (Chimweta et al., 2020). Highly hazardous pesticides from WHO class I and II are not recommended for use by smallholder farmers as they lack knowledge and resources for protecting themselves against these harmful pesticides exposure (Day et al., 2017). Selection of these highly hazardous pesticides by farmers at the Dzindi and the Tshiombo irrigation schemes may be attributed to availability, or accessibility and efficacy coupled with farmers experience on the insecticide.

Some smallholder farmers at the Dzindi and the Tshiombo irrigation schemes, believe that mixing pesticides, increasing recommended dosages, or applying them more frequently than recommended will enhance the control of *S. frugiperda*. This practice is often influenced by advice from neighbours and family members, highlighting a reliance on informal knowledge networks and a need for improved pesticide education and stewardship. In the absence of clear, research-based guidance, farmers often rely on informal recommendations from peers (CABI, 2019). Such informal information sharing is often based on hearsay is common among smallholder farmers, who are generally willing to try any method they believe might assist to control *S. frugiperda* (Asare-Nuamah, 2022). The use of pesticide cocktails is consistent with observations from Macate, Zimbabwe, where farmers mix two or more insecticides to control *S. frugiperda* (Baudron et al., 2019). However, the efficacy and cost-effectiveness of such insecticide cocktails still need to be thoroughly evaluated. As a result, these farmers actions on insecticides use may lead to evolution of resistance.

Smallholder farmers from the Dzindi irrigation scheme reported that Methomex ®900 SP is no longer effective in controlling *S. frugiperda*. Perception of insecticide efficacy on *S. frugiperda* vary among smallholder farmers worldwide. This is consistent with farmers from Mankweng and Ga-Mashashane (about 300 km from the Dzindi irrigation scheme) (Makgoba et al., 2021) and farmers from China's Yunnan province (Yang et al., 2021), Kenya (Kumela et al., 2019) and Zimbabwe (Baudron et al., 2019) who reported that Methomex ®900 SP has become less effective in controlling *S. frugiperda*. However, the majority of farmers in Ethiopia indicated that Ethiolathion, malathion and chlorpyrifos were effective in controlling *S. frugiperda* (Kumela et al., 2019).

Variations in the efficacy of different insecticides used to control *S. frugiperda* may be attributed to factors such as timing of application. As farmers from the Dzindi and the Tshiombo irrigation scheme lack monitoring tools and scouting skills, it is possible that in most cases they apply insecticides in the absence of the vulnerable life stage of *S. frugiperda*. Insecticides are only effective on early larval instars of *S. frugiperda* as older instars hide on maize whorls, feeding and using frass as a covering (Zhang et al., 2020) or use maize reproductive parts such as the whorl, ear or kernel that protect them from insecticide application (Pannuti et al., 2015). The best time of day for insecticide application is at dawn because young larvae hide in maize whorls during the day and become active during the night (FAO and CABI, 2019). However, farmers at the Dzindi and the Tshiombo irrigation schemes do not consider timing of application. They apply insecticides anytime of the day depending on the availability of labour or family members willing to assist them.

Farmers at the Dzindi irrigation scheme noted that they previously relied on indigenous knowledge to manage insect pests, but these traditional practices have mostly been discontinued. Similarly, farmers in Umtata (Eastern Cape), South Africa, have neglected indigenous methods for controlling certain maize insect pests, a shift that may be attributed to the promotion of chemical pesticides in these regions (Odeyemi et al., 2006). This is consistent with findings in Western Uttar Pradesh, where 60 % of farmers acknowledge organic farming and IPM as better alternatives to chemical pesticides in brinjal cultivation, yet many are still hesitant to adopt these methods and continue using conventional pesticides (Gore and Aryan, 2015). Having a high level of knowledge does not necessarily mean that farmers will put that knowledge into practice (Dewi et al., 2022).

During the period of survey, smallholder farmers at the Tshiombo irrigation scheme were solely dependent on insecticides without considering other alternatives in order to enhance control of *S. frugiperda*. Effective control of *S. frugiperda* requires IPM using the coordinated integration of multiple and complementary control strategies that reduce insect pest population in a safe, cost effective and environmentally friendly manner (Kogan, 1998). Smallholder farmers from Benin use insecticides (such as Emamectin benzoate, acetamiprid, cypermethrin and chlorpyriphos-cyhalothrin) with botanical pesticides (such as Yellow nutsedge, chan, shea tree, neem, tamarind and soybean) (Houngbo et al., 2020). Farmers from Zimbwabwe alternate insecticides with early planting, use improved seeds, uprooting and disposal of infested plants, use of washing detergent (OMO), and handpicking of eggs and larvae (Chimweta et al., 2020).

Only farmers at the Dzindi irrigation scheme had adopted Bt maize. This might be attributed to the fact that only the Dzindi irrigation scheme reported that they received training on Bt maize. Similarly, in the Eastern Cape, the farmers who attended the programme on Bt maize were the ones who adopted the technology (Kotey et al., 2017). The Dzindi irrigation scheme farmers indicated that regardless of high seed cost, Bt maize is economically effective. According to these farmers, Bt maize benefits include an increased yield and less labour due to non or less insecticide application. This is consistent with the results from the demonstration of Bt maize to smallholder farmers in Mpumalanga, Gauteng, North-West, Free State, Eastern Cape and KwaZulu-Natal provinces of South Africa that indicated higher yield due to less insect damage on Bt maize, reduce need for scouting and less labour for smallholder farmers who relied on knapsack for insecticide application as compared to conventional maize as main advantages of this technology (Keetch et al., 2005). In contrast famers in Christiana, North West province of South Africa viewed Bt maize as non-beneficial due to *B. fusca* evolving resistance in their area (Kruger et al., 2012).

Bt maize growers are required to plant a refuge area of non-Bt maize adjacent to their Bt maize fields in order to delay resistance development. Current refuge requirements are either a 20 % non-Bt planted (refuge) which may be sprayed with insecticides or a 5 % refuge area that may not be sprayed (Kruger et al., 2009). The Dzindi irrigation scheme farmers have been non-compliant to Bt maize planting. Most farmers did not plant refuge because they were not aware of the importance and consequences associated with not planting refuges. Farmers in Christiana and Standerton in Mpumalanga, South Africa, find refuge planting as being labour intensive and time consuming (Kruger et al., 2012). As a result, those who planted refuge preferred planting a 5 % refuge rather than a 20 % refuge, and applied insecticide on the refuge, resulting in it being ineffective. There is a need for proper training of farmers on Bt technology at the Dzindi irrigation scheme and a need for regular screening of evaluation of possible *S. frugiperda* evolving resistance to Bt maize.

In the Dzindi irrigation scheme, smallholder farmers do not intentionally plant structured refuges. However, because their fields are closely situated and they use different maize varieties, non-Bt maize planted by some farmers unintentionally serves as a refuge. This setup supports the survival of susceptible pest populations, helping to delay resistance development to Bt maize. Refuge strategies in such settings should therefore be explained in a way that acknowledges this informal system, encouraging coordinated planting and community-level awareness to strengthen resistance management efforts.

4.1. Conclusion

This study revealed that smallholder farmers at the Dzindi and Tshiombo irrigation schemes view *S. frugiperda* as a major threat to maize production. In response, many rely on informal and unsafe pest control practices—such as mixing pesticides and applying excessive doses—which pose health and environmental risks and contribute to insecticide resistance.

The findings highlight the urgent need for continuous farmer education on pest biology, safe pesticide use, and the correct planting and management of Bt maize. Educating farmers about the pest's life cycle will enable them to target it when it is most vulnerable, improving control outcomes. Additionally, integrating alternative approaches such as indigenous knowledge can strengthen pest management strategies by building on local practices and farmer experience.

In closely connected irrigation scheme communities, individual pest control actions influence neighbouring farms. Therefore, coordinated efforts and collaboration among farmers, extension officers, researchers, and agro-input providers are critical. Digital tools for pest scouting and monitoring should be accessible and easy to use to enhance decision-making. Effective management of *S. frugiperda* in smallholder systems requires a holistic, informed, and community-driven approach that values farmers' knowledge, promotes timely action, and empowers them to make safe and sustainable decisions.

CRediT authorship contribution statement

Phophi D. Nethononda: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Brett P. Hurley:** Visualization, Validation, Supervision, Data curation, Conceptualization. **Bernard Slippers:** Visualization, Validation, Supervision, Resources, Project administration, Funding acquisition, Data curation, Conceptualization. **Moraka N. Makhura:** Visualization, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Institutional review board statement

Ethics approval to conduct the study was granted from the University of Pretoria Research and Ethics Committee (ethics approval number is NAS309/2021).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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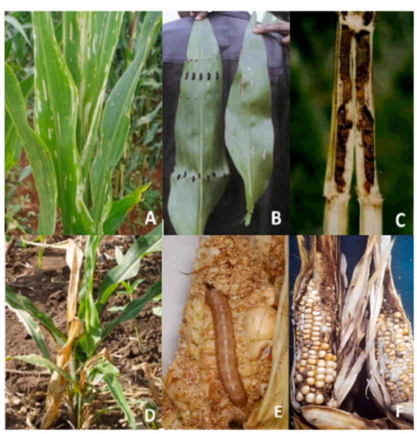
Appendix A. Topics for discussion at Focus Group Discussion

1. Which crops and cultivars do you cultivate?
2. Have you seen the following stages of this insect on your crops?

Photo by G. Ong'amo, N. Khadioli, B. Le Ru, N. Mujica, & P. Carhuapoma.

3. Have you seen the following damage symptoms on your maize?



OR

Photo by G. Ong'amo, N. Khadioli, B. Le Ru, N. Mujica, & P. Carhuapoma.

4. What do you call these insect pests?
5. What do you do when you see these insect pests?
6. Who gives you advice on the control strategy that you have selected to control these insect pests?
7. When do you apply that control strategy?
8. If you apply the control strategy, do you see any changes on the numbers of the insect pests?
9. If you observe any changes after control, how long do you observe those changes?
10. Do you think this insect pest affects your yield? Please elaborate
11. Is there anything that you would like to add or comment on?

Appendix B. Thematic analysis steps

Stage	Description
Familiarization with data	The researcher engaged deeply with the data through active participation, note-taking, and transcript reviews to understand farmers' viewpoints.
Initial code generation	Researchers generated initial themes based on farmers' knowledge, perception, and management practices of *S. frugiperda*.
Search for themes	Visual aids like mind maps and tables were used to organize and group codes into coherent themes, resulting in a structured framework with main themes, sub-themes, and relevant data excerpts.
Reviewing themes	Themes were reviewed to ensure adequate support from the data. Unsupported themes were consolidated or discarded.
Defining and naming themes	Themes were refined and named to align with the study's objectives, ensuring coherence and consistency.
Writing the report	The final stage involved composing the report, documenting the analysis process and theme derivation to ensure transparency and replicability.

Appendix C. Identified themes, sub-themes and some quotes from focus group discussion

Theme	Sub-theme	Quotes
1. Perception of *S. frugiperda* invasion at two the irrigation schemes.	Farmers awareness of *S. frugiperda*	"It is a problem" "We first saw it not long ago" "Wait until the first rain, all maize will be eaten by this pest" "Infestation is increasing everyday"
	Perceived impact on maize	"It causes a disaster" It is devastating We are always caring a knapsack because of it"
2. Knowledge of *S. frugiperda* life stages	Identification of *S. frugiperda* egg, larva, pupa and adult moth	"It has two heads" "It is Makonya" "We only see fresh frass as an indication of its presence"
3. Management practices	Current practices used to control *S. frugiperda*	" The extension officer gave us pesticides from the government" " We carry knapsack and spray"
4. Insecticides use for controlling *S. frugiperda*	Frequency of insecticides application	"As long as we apply insecticides every Monday" " A week after planting we just spray" "I kill it once with Tamron "
	Sources of insecticides	"We buy at Koporasi (NTK)" "Extension officer give us twice a year" "I get my insecticides at the hardware "
	Perceived effectiveness insecticides farmers use to control *S. frugiperda*	"*Spodoptera frugiperda* is not a problem it I mix insecticides " "Tamron is number 1 in controlling *S. frugiperda*"
5. Use of Bt maize to control *S. frugiperda*.	Source of knowledge about Bt maize	"That guy from Bayer told us about Bt maize" "We were taught in a workshop about Bt maize"
	Perceived effectiveness of Bt maize by smallholder farmers	" I prefer it because I no longer weed manually" "It has small grains compared to 701 cultivar but I plant it because *S. frugiperda* does not like it"
	Bt compliance/refuge planting	" I don't know what that packet is" "it's a buy one get free" "I only plant small packet (refuge) at home"

Data availability

Data will be made available on request.

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