Bindura University of Science Education

Fall armyworm management by smallholder maize farmers in the Zimbabwe Highveld

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A dissertation submitted in partial fulfilment of the requirements for the Master of Science Degree in Food Security and Sustainable Agriculture (Production)

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June 2019

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DECLARATION

I hereby declare that the research project entitled **"Fall armyworm management by smallholder maize farmers in the Zimbabwe Highveld"** submitted to Bindura University of Science Education, Department of Agricultural Economics, Education and Extension is a record of an original work done by me under the guidance and supervision of Professor **Innocent Wadzanayi Nyakudya** and this work is submitted in partial fulfilment of the requirements for the award of a Master of Science in Food Security and Sustainable Agriculture. The results embodied in this thesis have not been submitted to any University or Institute for the award of any degree of diploma.

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DEDICATION

I greatly dedicate this work to the Almighty God for grace and strength to complete this research. I would also like dedicate it to my mother Ruth and father Robert(late) in making it possible to do my first degree, which was stepping stone to this Master's Degree. Lastly but not least I would like to appreciate the support from my wife Josphine, and children Tinomudaishe, Kudakwashe, and Shamailla.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to everyone who helped me in various ways that enabled me to successfully produce this document. My first gratitude goes to Prof. I. W. Nyakudya and Mr. V.T. Munyati for constructive criticism, correction, and comments that enable me to produce a scientifically credible document. My appreciation also goes to AGRITEX officers in administration and the field. I would also like to thank Nozipo Nziramasanga, Kwadzanai Mushore, Noble Chipere, Taurai Matyora, Peter Ishe Muzofa, Eston Chasepa, Hardwick John Chiwashira, Lenard Jack, Goodmore Mubaiwa and Wellington Kanyongo. Your contribution to field work during the study is greatly appreciated and unforgettable.

ABSTRACT

Maize production by smallholder farmers in Zimbabwe plays a key role in national food security and livelihood options at the household level. This role has been threatened by the emergence of the fall armyworm (FAW) in Zimbabwe, a pest that predominantly feeds on maize. The aim of the study was to determine FAW management methods applied by smallholder maize farmers and factors that affect selection of control methods and use personal protective equipment. Data was collected from Makonde district ward 9 and Mazowe district ward 25, maize producing areas. The data was collected through the administration of a structured questionnaire, which was augmented with key informants' interviews and focus group discussions. Data collected through the structured questionnaire was analysed using the logistical regression model, where a statistically significant relationship was observed it was reported. Results showed that methods used to control FAW were mainly the application of chemical pesticides (76.4%) and crushing of larvae by hand (26.7%). The most commonly used FAW registered pesticides were Lambda cyhalothrin (32%), Emmamectin Benzoate (23.6%) and Carbaryl (9.8%). Non-registered pesticides commonly used pesticides were Methamidophos (3.6%) and Thunder (1.8%). Of the farmers who used chemical pesticides 46.7% perceived that they were effective in controlling the FAW. Only two out of nine registered active ingredients used by the farmers were applied while adhering to the recommended application rates. Fifty three percent (53%) of the farmers stated that they wore coveralls, whilst 52% stated that they wore gumboots, less than 15% wore the remaining recommended PPE. Twenty two percent (22%) did not have any particular clothes for spraying. The main sources of information on fall armyworm identification and control were extension services (58.3%), farmer friends (27.6%), radio (15.6%) and pesticide retailers (7.6%). Regression results showed that male farmers were more likely to use pesticides than female farmers, farmers who were trained on FAW identification and control were also more likely to use pesticides than those not trained. The trained farmers were also shown to be more likely to wear personal protective equipment than those who were not trained on FAW identification and control. This study also recommends the inclusion of standard measuring instruments in all pesticides containers; the pesticide label must include the application rates for 15 and 16 litres knapsack sprayers.

Keywords: Smallholder farmers, fall armyworm, pesticides, personal protective equipment, non-chemical control methods

LIST OF ACRONYMS AND ABBREVIATIONS

AGRITEX - Agricultural Technical and Extension Services

AI-Active Ingredient

Biopesticides-Biological Pesticides

DR&SS – Department of Research and Specialist Services

EC-Emulsifiable Concentrate

FAO – Food and Agriculture Organisation of the United Nations

FAW-Fall armyworm

FTLRP- Fast Track Land Resettlement Programme

GDP-Gross Domestic Product

GR-Granule

GMB-Grain Marketing Board

GOZ-Government of Zimbabwe

HH-Household Head

Icipe-The International Centre of Insect Physiology and Ecology

IPM-Integrated Pest Management

MLAWCRR-Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement

PPE-Personal Protective Equipment

SC-Suspension Concentrate

SL-Soluble Liquid

SP-Soluble Powder

WP-Water Soluble Powder

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

The economy of Zimbabwe is agro-based, with agriculture contributing about 14% of the GDP in 2012. Agriculture also makes a 67% contribution to the formal labour force (indirectly and directly) (Echanove, 2017). It is dominated by a number of crops namely cereals (maize, wheat, millet and sorghum), horticulture, legumes (soya beans, common bean, groundnuts and potato) and cash crops (tobacco, cotton, citrus, coffee, tea, sugar cane). The majority of the agricultural production comes from the smallholder farming sector, which make up 98% of the total farmers. These work on 73% of agricultural land and are responsible for 80% of the main staple food crop (maize) production (FAO 2012). Thus, maize is a very important cereal as its availability in adequate quantities translates to food security and also plays an important role in livelihoods options especially amongst smallholder farmers (Mazvimavi et al., 2012).

Therefore, any challenge that affect maize production has serious consequences on household incomes, food security and livelihoods. Despite their great contribution to food security and livelihood options, smallholder farmers in Zimbabwe are hampered by several challenges which affect maize productivity and production. These include poor maize marketing policy; unfavorable land policy thus lack of security of land tenure; pests and disease out breaks, inefficient production systems, climate change, and lack of collateral to access lines of credit (Munhande et al., 2013). The emergence of the fall armyworm added another layer to the problems faced by farmers in agricultural production and food security.

The fall armyworm (FAW) [*Spodoptera frugiperda* (J.E. Smith)] is a pest that is native to tropical and subtropical regions of the western hemisphere from the United States of America to Argentina (Rwomushana et al., 2018). It is a key pest of maize (*Zea mays L.*) and it feeds on more than 80 different plant species, including major crops such as cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.), soybean (*Glycine max* L. Merr.) and sugar cane (*Saccharum officinarum* L.)(Nagoshi et al., 2007; Montezano et al., 2018). The pest was first reported on Africa in early 2016 in West African countries which include Nigeria, Benin and Togo. By May 2017 the pest had spread to 14 East and Central African countries and 11 out of the 15 Southern African countries (Kumela et al., 2018; IITA, 2016).

The control of this new pest has been a problem because there are no effective scientifically proven control methods adapted for the region. There are no known natural enemies, which usually assist in its management. This has resulted in the use of various and at times unorthodox methods by farmers as they try to reduce economic losses (Bossuet, 2018). Fall armyworm's polyphagous nature also adds complexity to the designing and implementation of appropriate management strategies. This is because of the availability of alternative hosts which are outside the production season of main crops. In addition to its polyphagous nature, it is also a highly trans-boundary pest therefore the capacity to quickly infest the whole region and the whole country is very high (Johnson, 1987). Although its highly polyphagous in nature, there are two subpopulations of the fall armyworm from the Western Hemisphere, which exhibit different host plant distribution and certain physiological features (Pashley 1986; Juárez et al. 2012). There is the corn-strain(C-strain) which shows preference for sorghum and maize and the rice-strain(R-strain) which is consistently found in millet and grass species, associated with pasture habits (Nagoshi and Meagher 2004; Juárez et al. 2014). The C-strain which has preference for maize host been predominantly recorded in Africa and Zimbabwe. Which is a staple food crop in Sub-Saharan Africa, upon which over 300 million people depend (Abrahams et al., 2017). The R-strain is rare in Africa with a population less than 1% of the total FAW reported in Africa(Nagoshi 2019).

In Africa to date losses as a result of confirmed and suspected infestations of fall armyworm in rice, maize, sorghum and sugarcane have been estimated at USD13.38 million and in some instances accounting for over 70% yield loss (Abrahams et al., 2017; Rwomushana et al., 2018).

The main methods of control of the FAW in the Americas are pesticides and genetically modified crops, although it has developed some resistance to both (Horikoshi et al., 2016). Other methods used in the Americas include application of biopesticides such as *Bacillus thuringiensis* and other virus based biopesticides; mass rearing and subsequent release of predators and parasitoids (Prasanna et al., 2018). These methods are a bit expensive to many smallholder farmers and some form of subsidy from government is required. Classical biological control can also be utilised. Other methods which are of low cost although yet to be proven are cultural and mechanical control methods (Abrahams et al. 2017; FAO, 2018).

The definition of smallholder farmers in literature is dependent on country, context and ecological zone (Hazell, 2011). Smallholder farmers can be characterised as owners of small pieces of land on which they primarily grow crops for subsistence, rely almost exclusively on family labour and they usually face the challenge of resources compared to other farmers in the category or sector (Dixon et al., 2005). Pienaar and Traub (2015) defined the smallholder farming sector as generally exhibiting the following characteristics; use of small plots, which are labour intensive, use of traditional production techniques and at most times lack institutional support and capacity. The average size of land for smallholder farmers in Sub-Saharan Africa range from less than one hectare to a maximum of six hectares (FAO 2017). In this study smallholder farmers will be defined using the model from Pienaar and Traub (2015) and FAO (2017). The communal farmers, old resettlement farmers and A1 farmer fall within this definition of smallholder farmers in Zimbabwe.

When the pest was first observed by the smallholder farmers, they resorted to any method that they thought would control the pest and this included indiscriminate use of chemical pesticides. This includes highly toxic pesticides which are restricted for use by untrained farmers (Bossuet, 2018; Chimweta et al., 2019). Numerous studies have shown the challenges that smallholder farmers face when it comes to adhering to good agricultural practices in the use of pesticides (Magauzi et al., 2011; Maumbe & Swinton, 2003; Zimba & Zimudzi, 2016; Zinyemba et al., 2018). They fail to adhere to pre-harvest intervals, do not wear appropriate personal protective equipment and at times fail to understand the pesticide label instructions (Ngolo et al., 2018). Various studies have also shown that farmers may be involved in overuse of pesticides as they try to control different pests this is as a result of having limited information about the occurrence of the pest and appropriate methods of control. At times they have their own perceptions about pest pesticide management and thus make their own decisions based on various factors and criteria (Hashemi & Damalas, 2010; Mattah et al., 2015). When farmers indiscriminately use pesticides, they expose themselves and their families to acute and chronic poisoning inevitably negatively affecting their health (Oesterlund et al., 2014). This also results in a number of negative environmental effects such as water pollution, soil pollution, poisoning of livestock and other non-target species (Henry & Feola, 2013).

Since the first report of the fall armyworm was documented in Africa, there has not been much documented systematic studies done on the pest management practices of smallholder farmers. Most of the information on farmers coping mechanisms comes from country and media reports.

Some studies have been done in Ethiopia, Kenya, Zimbabwe and Rwanda (Baudron et al., 2019; Chimweta et al., 2019; Hanyurwimfura et al., 2018; Kumela et al., 2018). In Ethiopia and Kenya, the study focused only on knowledge, attitudes and practices of smallholder farmers in the face of the fall armyworm and not much on their pesticide management practices (Kumela et al., 2018). In Rwanda the study focused more on the development of an FAW an monitoring system (Hanyurwimfura et al., 2018). In Zimbabwe the study was focused on understanding the factors influencing fall armyworm damage in African smallholder maize fields and quantifying its impact on yield (Baudron et al., 2019). Another study in Zimbabwe focused on the management of the pest by farmers in flood-recession cropping arears in Zimbabwe (Chimweta et al., 2019) which are different ecosystems from the rainfed farming. This study focused on determining the methods used by smallholder farmers in controlling the FAW in the Zimbabwe Highveld, and the factors that affected selection of the methods used and use of PPE.

Most smallholder farmers in Zimbabwe do not use pesticides in maize during the production phase but on post-harvest crop protection. Pesticide use during the production phase is more knowledge intensive and requires specialised training than use during post-harvest. Most of these smallholder farmers do not have these skill set, but are now using pesticides. They may end up using pesticides that has negative implications on their health and the environment (Mulilamitti, 2017). Thus, the need to carry out this study. The assessment of smallholder maize farmers fall armyworm and pesticide management practices plays a critical role in designing appropriate extension strategies for the control of the pest, that meet the farmer's needs. It also aids in setting up research agenda and formulation of research that is sensitive to farmers demand and also coming up with policy recommendations that are demand driven and relevant to farmers (Khan & Damalas, 2015). This is a crucial step in the plan for developing and implementing strategies that promote good agricultural practice especially focusing on judicious pesticide use (Mengistie, et al., 2015).

1.2 Problem statement

The FAW is a new invasive pest, that is a threat to agricultural production. It is polyphagous in nature hence it has a wide host range. However, the most common strain has preference for maize, which is the staple food for the majority of Zimbabweans. The pest has been shown to cause more than 30% reduction in maize yield (Abrahams et al., 2017; Rwomushana et al., 2018). Thus, posing a great threat to national food security. The pest was introduced into the region and country already pre-loaded with resistance to some conventional pesticides (Midega et al., 2018). The problem that the country is facing as a result of the pest is mainly due to the fact that there are no country specific control mechanisms to manage the pest. A significant proportion of the crop preferred by the pest is produced by smallholders in Zimbabwe (Echanove, 2017). The majority of these smallholder farmers do not use pesticides for pre-harvest crop protection hence have no practical knowledge of the subject matter.

1.3 Objectives

1.3.1 Main objective

To determine fall armyworm management methods applied by smallholder maize farmers and factors that affect selection of methods used, and use of personal protective equipment.

1.3.2 Specific objectives

1.3.2.1 To determine the methods being used by smallholder farmers in controlling the fall armyworm in maize and their perceived effectiveness.

1.3.2.2 To determine chemical pesticides and the application rates being used by smallholder farmers in controlling the fall armyworm in maize.

1.3.2.3 To determine pesticide risk mitigation measures used by smallholder farmers in controlling fall armyworm.

1.3.2.4 To determine the factors that affect selection of fall armyworm control methods by smallholder farmers.

1.3.2.5 To determine the factors that influence the selection and use of personal protective equipment by smallholder farmers.

1.4 Research questions

1.4.1 What are the non-chemical methods being used by farmers to control the fall armyworm?

1.4.2 What is the perceived effectiveness of the methods being used by farmers in controlling the fall armyworm?

1.4.3 What are the chemical pesticides and the application rates used by smallholder farmers in controlling that fall armyworm in maize?

1.4.5 Which personal protective equipment is worn by farmers for reducing risks associated with use of pesticides in controlling the fall armyworm?

1.4.6 What are the factors affecting selection of fall armyworm control methods and use of personal protective equipment by smallholder farmers?

1.5 Justification

The staple cereal of Zimbabwe is maize and a large proportion of the crop is grown by smallholder farmers (FAO 2012). This implies that any problem that results in low maize production and productivity has a significant impact on food security and people's livelihoods in Zimbabwe. The FAW, a new pest in the region and Zimbabwe in particular, has great potential to affect food security and livelihoods at household level. It has potential to also affect other crops which are not food crops since it has a host range of over 80 different plant including major crops such as cotton, wheat, groundnuts, soybean and sugar cane (Nagoshi et al., 2007). This has also a great potential to negatively affect the economy of Zimbabwe which is agro-based with over 67% of the population being employed by agriculture related activities indirectly and directly (Echanove, 2017). However, with this threat to the country there is not much study done locally to investigate how farmers are managing the pest and pesticides related to its control, and also how effective are government structures put in place to help farmers control the pest. This study intends to investigate the above-mentioned issues so as to contribute to the body of knowledge fill the gap in literature. It also aims at generating information that will aid in government policy for the effective and sustainable management of the FAW. The end result will be enhanced production and productivity by smallholder farmers, which will improve food security, better livelihoods and sustainable pesticide use.

1.6 Scope/delimitations and limitations of study

The study is focusing on maize farmers in high production regions and neglects those in semi-arid areas. Those not selected from the study may be utilising pest and pesticide management practices different from those used in the study and which are worth studying. However, the study lays a foundation for future research on the area under study.

1.7 Outline of the Thesis

This section presents the structure of the thesis which is broken down into six chapters.

Chapter 1: Introduction

This chapter describes the background to the study which outlined issues that relate to the challenge of the FAW in maize production and how this affected the smallholder farmers. The problem statement highlighted the problem of the FAW and its threat to food security and livelihood options. The objectives and research questions for the purpose of the study were also described. The justification of the study covered the information gap the researcher intends to fill as he studies how smallholder farmers in Zimbabwe are managing the FAW. Boundaries for the study in different aspects were given by the researcher under scope and delimitations of the study.

Chapter 2: Literature Review

The literature review summarised the origin of the pest, the various management options that have been used and those have potential to control it. It also outlined the potential effects on smallholder farmers, livelihood options, food security and also economic impacts on the nation of Zimbabwe if the pest in not sustainably managed. The theoretical and conceptual frameworks employed in the study were also highlighted in this chapter.

Chapter 3: Methodology

This chapter describes the study sites, research design, sampling frame work, data collection and analysis procedure used by the researcher in this study. It also highlights how the researcher addressed ethical considerations related to the study.

Chapter 4: Results

The chapter summaries the data obtained in the study and the statistically significant relationships reported.

Chapter 5: Discussion

Chapter five discusses the reported results and how they are related to literature.

Chapter 6: Conclusions and Recommendations

This chapter summaries the obtained results and the degree to which the objectives of the study were met. It also gives recommendations on areas that need attention basing on the results obtained from the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Maize is the staple food in Zimbabwe and is a key determinant of household food security and livelihood options amongst smallholder farmers, who produce 80% of maize in the country. The emergence of the FAW, a pest that has been confirmed to preferably attack maize is a great threat to national food security and livelihood options. Studies done in Zimbabwe have shown that potential yield loss as a result of the pest range from 11.5% to 58% which have also been estimated to be between US$ 76 million to US$ 191 million per annum in monetary terms (Baudron et al., 2019; Chimweta et al., 2019). Thus, there is a need to understand the current pest and pesticide management practices by smallholder farmers as they try to control the pest. This will aid in the in the development and implementation of more sustainable strategies to control the pest.

2.2.1 Origin, Distribution and Impact of Fall armyworm

The FAW is a nocturnal moth, but the larval stage of its life cycle is the one that causes economic damage to crops. It is a pest that is native to tropical and subtropical regions of the western hemisphere from the United States of America to Argentina (Rwomushana et al., 2018). The caterpillar is a major pest of forage grasses, cereals and has been recorded as feeding on 186 plant species from 42 families (Early et al., 2018). These include crops of economic importance such as maize, sorghum, cotton, and sugarcane. (Nagoshi et al. 2007). It was first reported on the continent of Africa in January 2016 initially in Nigeria, then Benin, Sao Tomé and Togo (Stokstad, 2017; Prasanna et al., 2018). By end of 2018 it had been confirmed to be present in over 44 countries in Africa including Madagascar (Rwomushana et al., 2018). The FAW moth has a migratory behavior thus a high dispersal capacity. The lifecycle varies according to seasons, in summer the lifecycle is 30 days (average daily temperature of ~28°C), 60 days in spring and between 80-90 days during the winter. It does not undergo diapause, so infestations take place continuously throughout the year in arears where its endemic (Abrahams et al., 2017; Prasanna et al., 2018).

The FAW species can be found existing in nature in two separate though morphologically identical strains the R-strain(rice-strain) and C-strain(corn-strain) which are host specific. The R- strain prefers rice, *Oryza sativa* (L.), and bermudagrass, *Cyndon dactylon* (L.) Pers. and other Graminaceae, whilst the C-strain prefers maize, and cotton. The fall armyworm is highly polyphagous partly because these two strains have different host species preference (L. M. Juárez et al., 2012). Its highly probable that the C-strain that prefers maize, is the one that invaded Africa, as evidenced by the continuous attack of maize in Africa. Further research needs to be conducted to confirm this (Prasanna et al., 2018). Maize is a staple food for over 300 million African families; thus, the pest poses a threat to food security, nutrition and livelihoods (Prasanna et al., 2018). In Zimbabwe estimated losses ranging from 9.24% up to 58% 11.57(Baudron et al., 2019; Chimweta et al., 2019) have been observed. The pest has been reported to have a potential to cause estimated maize yield losses between US$76 and $191 million if proper control measures are not implemented in Zimbabwe (Devi, 2018).

2.2.2 Smallholder maize production in Zimbabwe

The majority of the agricultural production comes from the smallholder farming sector, which make up 98% of the total farmers. Maize is mainly grown by smallholder farmers under rainfed conditions and the farmers at times experience perennial food shortages due to increased rainfall variability especially with the climate change phenomena (Zinyengere et al., 2011).

2.2.2.1 The fall army worm and maize production in Zimbabwe

The first confirmed case of FAW in Zimbabwe was reported in October 2016, however, there is evidence to suggest that there is evidence to suggest that damage was first noted in 2014 but was passed off as due to “a-difficult-to-control” stem-borer (Chinwada, 2019). Studies by the Plant Protection Research Institute in Zimbabwe indicate that by the end of 2016 11% of farmers in Zimbabwe had experienced the pest and by 2017 more than 60% had experienced the pest (PPRI, 2019). Studies in Zimbabwe on the potential yield loss as a result of the FAW include 11.57% mean from Chipinge and Makoni district (Baudron et al., 2019) and 58% from the Zambezi Valley (Chimweta et al., 2019). In the fight against the fall armyworm in Zimbabwe there are several products that have been temporarily registered against the pest and these include; emmamectin benzoate, emmamectin benzoate and acetamiprid, flubendiamide, deltamethrin and pirimiphos methyl, gamma cyhalothrin, spinetoram and methoxyfenozide, carbaryl , chlorantraniliprole, chlorantraniliprole and lambda cyhalothrin, flubendiamide and thiacloprid and indoxacarb and acetamiprid(GOZ, 2019). To date 45% of the farmers in

Zimbabwe, 257 extension supervisors have been trained in the identification and control of the FAW (AGRITEX, 2019; PPRI, 2019). A FAW early warning system has also been set up with the assistance from IRLCO-CSA and FAO, with 848 pheromone traps having been set up in 60 districts in Zimbabwe.

2.2.2.2 Smallholder farmers and pesticide-related risks

The level of safe pesticide management among smallholder farmers especially in developing countries is low (Maumbe & Swinton, 2003; Mengistie et al., 2015; Zimba & Zimudzi, 2016; Zinyemba et al., 2018). This improper use results in direct poisoning and indirect poisoning, consumption of food with pesticide residues above Maximum Residue Limits (MRLs). It also results in pesticide resistance among insects and contamination of the environment (Ngolo et al., 2018). Less than 20% of the global pesticides is consumed by the developing countries however, 70% of the total cases of acute poisoning takes place in the developing countries (Oesterlund et al., 2014)). This has led to the banning of numerous pesticides through use of various conventions such as the Rotterdam Convention, Stockholm Convention and Basel Convention.

The use of PPE is normally thought as the first line of defence against pesticide- related injury but according to the hierarchy of risk reduction by FAO,2016 this is the last option. The first option is elimination of highly hazardous pesticides, followed by awareness on the dangers of pesticide exposure and then PPE (FAO, 2016). Use of PPE is not always practical especially in regions with hot climatic conditions. The cost of PPE is at most times high for smallholder farmers. Studies have also shown smallholder farmers reluctance to wear PPE (Okoffo et al., 2016; Ugwu et al., 2015; Yassin et al., 2002). Softer chemistry pesticides (WHO class II and class III) and GHS colour code blue and green are being promoted as safer alternatives to the class 1a and 1b WHO and yellow and red on GHS. The list of less toxic alternatives also includes botanical pesticides, bio-pesticides and biologicals among other methods used in integrated pest management.

2.2.2.3 Factors that affect selection of FAW control methods by smallholder farmers

It is important that sustainable strategies be used in the fight against the FAW and not rely heavily on the use of pesticides. In a manner that does not cause harm to human life and the environment. There is no adequate information on the methods being used by smallholder farmers in Zimbabwe to control the FAW and the factors contributing to the use of these methods. Studies in other countries have shown that even if farmers have knowledge of the health impacts of some of these methods as indiscriminate pesticide use, they may not practice according to the knowledge they have (Yassin et al., 2002). It becomes very important to understand their knowledge, attitude and practices so as to take action where it is needed. A key objective would be to ensure that policies and practices are not promoting overuse, of pesticides as there are other mechanisms that can effectively address and improve smallholder farmers FAW control methods.

2.2.3 Fall armyworm management methods and their potential effectiveness

The FAW invaded the continent with aggressiveness and governments were not prepared for it, this led to a quick response through use of chemicals pesticides. Agronomic management methods are more sustainable and could also be affordable to resource constrained smallholder farmers. However credible information about the most effective agronomic practices for the control of FAW under typical African smallholder is still being generated through research (Baudron et al., 2019).

In the management of the FAW there are two broad categories that can be used and these are; methods that reduce possibility of damage occurring for example habitat management and resistant crop varieties; and methods that reduce the level of economic damage when the crop has already been attacked such as use of crop protection products, releasing of natural enemies and hand picking of insects (Rwomushana et al., 2018).

2.2.3.1 Agronomic and cultural methods

Fall armyworm does not undergo diapause, hence methods that aim at suppressing overwintering populations are not effective in an annual cropping system. However cultural methods do have the capacity to reduce FAW population during the production season (Hardke et al., 2015). Intercropping maize with drought-tolerant green leaf desmodium, *Desmodium intortum* (Mill.) Urb., and planting *Brachiaria* cv Mulato II as a border crop around the crop has been shown as an effective method in controlling the pest (Midega et al., 2018). This push-pull technology was developed by the International Centre of Insect Physiology and Ecology (icipe) and its partners was shown able to reduce FAW infestation by 80% in plots where the technology is used. The technology is environmentally friendly and cost-effective for management of the pest. In as much as the push-pull is very effective, the adoption of the technology is relatively low, due to various reasons which include knowledge intensiveness of the technology, increased labour requirements, adaptation of the technology to existing farming systems and access to seed (Rwomushana et al., 2018). The companion crops are also potentially weedy and or invasive (Witt and Luke, 2017).

Early planting in some cases allows the crop to escape FAW attack if the pest is migrating from another area, but if it's endemic it may not be very effective. Late planting and staggering of planting should be avoided as this would continue to provide favored food (FAO, 2018). In farm field schools in Kenya it was shown that the late planted crop suffered greater losses. Studies have also been done in Africa which show that intercropping maize with food legume crop such as sugar beans, soybean and groundnuts can reduce fall armyworm damage by 30%,21% and 31% respectively (Hailu et al., 2018). However, some legumes have been noted as hosts for the FAW in the Americas. Some smallholder farmers use herbicides, which are selective for maize only and thus they will kill the legumes. Handpicking of caterpillars and egg masses has also been shown to be an effective method in the first line of defence by smallholder farmers in Africa (Prasanna et al., 2018).

2.2.3.2 Biological Control

The control of FAW through use of biological control covers several methods which include encouragement of local natural enemies, classical biological control and inundative releases. Biological control offers the great advantage of being environmentally safe and more sustainable alternative FAW control measure. However, the success of biological control depends on understanding the adaptation and establishment of applied biological control agents in agricultural ecosystems (Mahmoud, 2017).

Biological control involves the introduction of a natural enemy into an environment in which, it is not present. It's mostly used for a pest that has invaded a new area and there are no natural enemies that can be used in its control. The egg parasitoid *Telenomus remus* was suggested as suitable candidate for introduction as reported from Cote d'Ivoire and South Africa (Abrahams et al., 2017). Other parasitoids being investigated for efficacy in Africa include the egg-larval parasitoid *Chelonus insularis* and the larval parasitoid *Cotesia marginiventris* (Abrahams et al., 2017; Sisay et al., 2018). *Trichogramma* spp egg parasitoids have been successfully used, in the Americas and commercial products of *Trichogramma pretiosum* are registered for use against fall armyworm in Brazil. The *Trichogramma* spp. are commercially available in Africa, so they, along with indigenous species, should be studied for possible control of the FAW.

Parasitoids *Cotesia icipe*, *Palexorista zonata*, *Charops ater* and *Coccygidium luteum*, were studied in Kenya, Tanzania and Ethiopia and they exhibited 45%, 12.5%, 12% and 8.3% field parasitism, respectively (Sisay et al., 2018; Tefera et al., 2018)

2.2.3.3 Botanicals

Many plant species possess insecticidal properties, which can be used to control pests. The active ingredients of some of these plants, or their synthesized equivalents, form the basis for formulated products, and various local concoctions also use such plants (Rwomushana et al., 2018). The use of botanical pesticides is considered as a sustainable substitute to hazardous synthetic pesticides. Botanical pesticides have been in use by farmers of developing countries for centuries to control insect pests in stored produce and field crops (Schmutterer, 2009).

Botanicals such as the neem extract (Azadirachtin) and chinaberry extract have been used to control the FAW in Brazil and Paraguay respectively. In Costa Rica a concoction of neem, garlic extract and detergent have also been used effectively against the fall armyworm (Prédes Trindade et al., 2015; Abrahams et al., 2017). In Ghana three products which are based on Azadirachtin are registered against the FAW. Other botanicals such as the Oxymatrine and matrine (found in *Sophora* spp) have been reported as effective against FAW in the field and laboratory bioassays respectively in the Americas. They have potential to control the FAW in Africa and should be studied further since they are already registered in some countries for other pests. Orange oil, garlic oil and maltodextrin have been shown to be effective against related pests so are candidates to be tested against the FAW. Pyrethrins (from *Chrysanthemum cinerariaefolium*) are effective against FAW and registered in Africa, but have non-target risks that require mitigation. Extracts from Argemone *ochroleuca* Sweet (Papaveraceae) , Boldo, *Peumus boldus* Molina (Monimiaceae) , jabuticabeira, *Myrciaria cauliflora* [Mart.] O. Berg (Myrtaceae) have also been shown to be effective against the fall armyworm Ethiopia (Sisay et., 2019).Studies in Mexico have also shown that extracts *Myrtillocactus geometrizans and Couroupita guianensis* are possible products for the control of *Spodoptera* due to their larvicidal activity (Rwomushana et al., 2018).

2.2.3.4 Pheromone Lure

One of the key strategies in the control of the FAW is to detect infestations before they cause economic damage and this can be achieved by using traps (Prédes Trindade et al., 2015). This can be achieved through use of pheromone traps. Pheromones are used in a multicomponent system in which the pheromone act as lure in trap (Mitchell et al., 1989). The traps can determine the presence or absence of the pest, but generally good indicators of density. In the USA FAW pheromone traps have been shown to be a useful tool monitoring FAW males (Mitchell et al., 1989). Pheromone traps can be used either for trapping or for mating disruption; in trapping the objective is to reduce the male population to an extent that females are unable to mate (Rwomushana et al., 2018). In mating disruption much pheromone is released into the environment such that males become confused and fail to locate females, since the female's pheromone is lost in the cloud of the synthetic pheromone. Mating disruption is not yet that sustainable as pheromone production is expensive. Currently trials are being conducted in East Africa to check the effectiveness of the mating disruption approach (Rwomushana et al., 2018). Using pheromones in the control of the FAW is more effective if applied over a large area

2.2.3.5 Synthetic Pesticides

Synthetic insecticides were one of the first line defence methods used by governments and farmers when the FAW invaded the continent. This is also true for many insect pest species; insecticides are an important component of the management strategy. Governments in an effort to manage resistance have been recommending a range of active ingredients and products. Efficacy trials to allow label extensions on already registered products which do not have FAW have also been used by regulatory authorities (Abrahams et al., 2017; Rwomushana et al., 2018).

Studies have shown that farmers are using all sorts of pesticides including those under restricted use category and those classified as highly hazardous (WHO class 1a and 1b) (Chimweta et al., 2019). A key challenge in the use of pesticides by farmers in Africa is the risk to human health and the environment that occurs when farmers fail to practice judicious pesticides use. Resource constrained farmers are often unwilling or cannot afford to buy the recommended personal protective equipment (PPE). At times the PPE is not user friendly considering the hot climatic conditions in Africa (Oesterlund et al., 2014). Farmer surveys have shown pesticides as the commonest control method used by farmers. However, farmers believed they were not as efficacious as they wanted them to be (Rwomushana et al., 2018). This may be due to inappropriate use, such as wrong dosage, incorrect application rate, and use of fake or adulterated products (Baudron et al., 2019; Kumela et al., 2018).

Some of the insecticides being used by farmers in controlling the FAW include carbaryl, cypermethrin, deltamethrin, lambda-cyhalothrin, profenofos, permethrin, imidacloprid, dichlorvos, lambda cyhalothrin and profenofos, acetamiprid, dimethoate, beta cyfluthrin, methamidophos, trichlorfon, diazinon, triadimenol, fipronil, aluminium phosphide, chlorpyrifos, emmamectin benzoate, triadimenol and *Bacillus thuringiensis* (Bt.) (Chimweta et al., 2019; Rwomushana et al., 2018; Togola et al., 2018). The Government of Zimbabwe (GOZ) through the command agriculture program issued out insecticides which include macten, super dash, nemesis, lambda cyhalothrin, tide, tide plus and carbaryl. Although no data is yet available in Africa to show pesticide resistance, some of the pesticides widely being used in Africa belong to the mode-of-action classes to which resistance has been confirmed in the Americas (Yu, 1991). These include pyrethroids (lambda cyhalothrin, cypermethrin, permethrin fenvalerate and fluvalinate), organophosphates (diazinon, chlorpyrifos, malathion, methyl parathion, and trichlorfon), and carbamates (carbaryl, methomyl, and thiodicarb) (Hardke et al., 2015; Horikoshi et al., 2016; Yu, 1991).

FORTENZA™ Duo (Cyantraniliprole + Thiamethoxam) a seed treatment product based on cyantraniliprole and thiamethoxam is being promoted by Syngenta and African Development Bank as a possible control mechanism for the pest. Seed treatment trials from Zambia suggest the product offers protection to the seedlings up to 4 weeks and potentially saves the farmer 1- 3 foliar insecticide sprays in commercial farms. The efficacy of the seed treatment may be affected by soil type, as seed sown in sandy soils emerges faster and benefits from longer protection than seed sown in loamy or clay soils (TAAT, 2019).

2.2.3.6 Host Plant Resistance

The technology has great potential in the fight against the FAW especially in Africa, where a large number of farmers are smallholder who have limited capacity to access affordable and safe FAW control methods. Ten promising CIMMYT maize in-breeds have been identified and validated in Kenya (Rwomushana et al., 2018). There are five materials that have shown great potential and may be available within the next 2-3 years. This also needs to be coupled with an accelerated breeding program for Africa- adapted varieties with fall armyworm resistance in addition to farmer-preferred traits, leading to the release and deployment of second-generation FAW maize hybrids/OPVs in the coming years (Hardke et al., 2015).

2.2.3.7 Other methods

Farmers have also used their own methods as they tried to control the FAW, in addition to the use of pesticides and bio-pesticides. These include hand picking and crushing the caterpillars and egg; applying ash, sand, urea, detergents (OMO); use of fish soup to attract natural enemies and destroying infected plants. They also spayed solutions of water and diseased larvae, to avoid higher pest populations. Hand picking was perceived as somewhat effective in Namibia but in Ghana 76% and Zambia 61.9 reported the method ineffective. Further studies are required to establish the actual costs and benefits of handpicking larvae in terms of FAW damage, yield and the cost-benefit related to the method (Mulilamiti,2017; FAO, 2018a; Rwomushana et al., 2018).

2.3 Conceptual/theoretical framework/s

2.3.1 Theoretical framework on sustainable pest management

Insect pest cause substantial losses to agricultural production globally but the loses is much more observed in developing countries and among smallholder farmers who mostly face resource constraints (Mengistie et al., 2015). However, when the insect pest is an invasive one the magnitude of the loss becomes even worse even to levels of total crop write-off (100% yield loss observed). By definition invasive alien species refer to species that are "non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health (CBD, 2004). These species are considered to be one of the biggest threats to ecosystems of the earth, and also to the services that they provide to humanity (Kaiser ,1999). They tend to be multi-sectorial in their impact and hence the need to be addressed through use of a multisectoral approach (Cock,2003). In the context of the fall armyworm invasion, the pest has a host range of more than 80 plant species and some of which are crops of economic importance (Hanyurwimfura et al., 2018). This means the impact of the pest is not only felt at smallholder farmer level but national, regional and international as it has potential to affect trade through SPS issues (Jeger et al., 2017). Nationally the pest also has a bearing as the economy of Zimbabwe and other sub Saharan Africa in which the pest was reported are agro-based (Abrahams et al., 2017).

One of the key sectors in the multisectoral approach in dealing with the fall armyworm invasive pest, are the smallholders' maize producers. These are the ones who have potential to face the greatest impact. They are mostly resource constrained, have limited access to information, heavily reliant on maize as a cash crop and for food security and when they use pesticides, they use them in a manner that is detrimental to their health and the environment. Thus, the need to study their systems and how best to help them in the first line of defence against the pest. They also contribute over 75% of agricultural production in their nations and so are key to food security (Samberg et al., 2016).

2.3.2 Conceptual framework

The framework used in this study emanates from the complex situation in which smallholder maize farmers in Zimbabwe found themselves faced with when the fall armyworm an invasive pest invaded Zimbabwe. This study is focusing on how they copied in the wake of a pest that was a threat to food security and livelihood options. Which chemical and non-chemical methods did they use and the effectiveness of these pest control mechanisms? It also access's the government led interventions that are being used to try and mitigate against the potential threat to food security as a result of this pest.

2.4 Summary of literature Review

The fall armyworm a new invasive pest in Zimbabwe and Africa is a great threat to food security and livelihood options in sub Saharan Africa and Asia. It is highly polyphagous in nature but prefers cereals and maize in particular as observed in the countries in which it was reported. The pest is not only a challenge to food security but also economies of countries in the SSA due to the fact that their economies are agro-based. It also presents challenges to human health and the environment, as smallholder farmers try to control it without practicing judicious pesticide use. This is due to the fact that a substantial amount of the cereal crop maize in Zimbabwe and other countries in which it was reported is produced by smallholder farmers. Since it's a new pest and they have no experience with the pest and there is also little information available in sustainable management of the pest they end up using the only method they know to control insects which is pesticide use. There is need to keep on conducting research on sustainable control methods and quickly disseminate it to smallholder farmers. This should be backed by sound policy so that its effective and sustainable.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The chapter provides a description of the research methodology used in carrying out this study. It outlines methods used to collect primary and secondary data. Primary data was collected through a structured questionnaire and semi-structured interviews. Whilst secondary data was collected from various sources which include the internet, and government departments reports. This chapter covers the description of study sites, research design, sampling procedure, data collection procedure, data analysis procedure, and ethical considerations.

3.2 Description of study sites

The study was conducted in Mashonaland West and Mashonaland Central provinces in Makonde and Mazowe districts respectively. Mashonaland West and Mashonaland Central are the highest maize producing province's in the country and regarded as the bread basket of Zimbabwe (MAMID 2017). Mashonaland West province has a population of 1 501 656, representing about 11.5% of the total population in Zimbabwe and covers 57 441 square kilometres (Zimbabwe National Statistics 2012). The population of Makonde is 67 728, which 4.5% of the Mashonaland West Province. Ninety eight percent (98%) of the people in Makonde district is based in the rural area (Zimbabwe National Statistics, 2012).

Mashonaland Central province has a population of 1 152 520, representing about 8.8% of the total population in Zimbabwe and covers 28 347 square kilometres. The population of Mazowe is 233 450, which is approximately 20.3% of the Mashonaland Central Province. It is estimated that 97.2% of the people in Mazowe district are based in the rural area's (Zimbabwe National Statistics, 2012a). The chosen districts lie in agro-ecological regions II which receive between 750-1000mm rainfall per annum. Natural region II occupies approximately 15% of the total Zimbabwean land area and accounts for 75% to 80 % of the area planted to crops in Zimbabwe (Odunze et al.,2015).

In Makonde district, the study was conducted in ward 9. The ward was divided into three areas basing on the soil type and commonly grown crops. Sub-ward A is located (17º28.9960'S; 30º10.5300'E) has sandy soil type and commonly grows maize and tobacco. Sub-ward B is located (17º24.4190'S; 30º3.0130'E) has loam soils and commonly grows maize and cotton. Sub-ward C is located at (17º21.6340’S; 30º0.2260’E) has heavy clay soils and commonly grows maize and soybeans. The mean annual rainfall is 816 mm whilst the mean annual temperature is 19.8°C(Climatedata 2019a). In Mazowe district the study was conducted in ward 25 on Rivers farm village (17º17.5230’S; 30º51.7940’E), Wengi farm village (17º29.6510’S; 30º88.1360’E) and Ethel grange farm village (17º24.4310’S; 30º86.4960’E). The mean annual rainfall is 901mm whilst the mean annual temperature is 18.2°C (Climatedata 2019b). The soil type is predominantly sandy loamy with maize and tobacco being the commonly grown crops by the A1 farmers.

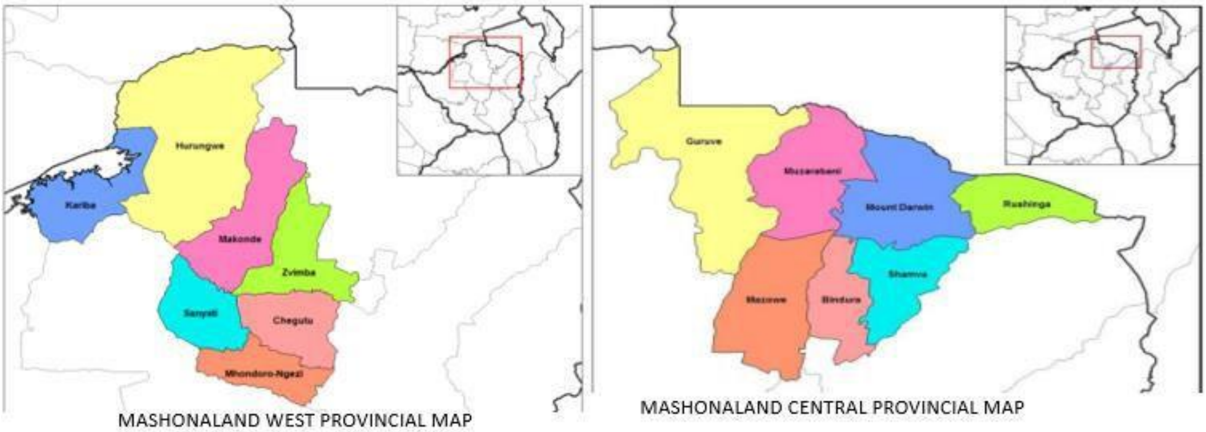

Figure 3. 1 Study sites www.googlemaps.com

3.3 Research design

This study used the explanatory sequential mixed approach methodology. The explanatory sequential mixed approach enabled the study to combine the strengths of the quantitative and qualitative approaches. Quantitative methodology enabled objective measurements to be done and robust statistical data analysis to be conducted. This then allowed for inference to be done in areas where the research was not conducted. The study has greater repeatability due to its quantitative and objective nature of quantitative methodology. However, quantitative methodologies tend to be too abstract. Not all-important components in a study can be measured in numbers as in certain instances the objective explanation of quantitative data gives value to it. The qualitative approach enabled an explanation of the data collected through the quantitative methodology. The mixed approach combines the robustness and repeatability of the quantitative methodology and the exploratory nature of the qualitative methodology. Hence observed knowledge, attitudes and practices data can be explained from the information gathered through the qualitative approach (Creswell 2014; Kumar 2011).

A semi-quantitative questionnaire was used as a tool in the quantitative approach. In the qualitative approach focus group discussions, key informant interviews and the researcher were used as tools of data collection. Secondary data were obtained from government departments reports, private sector reports, peer reviewed articles and journals from the internet.

3.4 Sampling procedure

Judgmental sampling was used in selecting the two provinces and the respective wards. Quota sampling was then used to select the appropriate number of respondents within the wards. This was done basing on the percentage contribution of the individual ward to the combined total population of the two wards. Simple random sampling was then used to select the village in the ward and selecting the respondents for the questionnaire. Simple random sampling was used to select the respondents for the focus group discussions, whilst judgmental sampling was used to select the respondents for the key informant interviews.

The respondents who were interviewed in the study were all drawn from Makonde district ward 9 and Mazowe district ward 25, A1 model smallholder farmers. The combined sampling frame from the two wards was 1315 with 559 being from ward 9 and 756 from ward 25. A sample size of 225 drawn from the 1315 target population as calculated using RAO soft with a 99% confidence interval and 5% margin of error was used for the study (James et al., 2014; Raosoft, 2017).

3.4.1 Selection of Provinces

Judgmental sampling is a non-probability sampling technique, in which a sample is selected by focusing on particular characteristics of a population that are of interest. These characteristics enable the researcher to answer the research questions and achieve the objectives of the study (Creswell 2014). The particular characteristic of relevance in this study was the FAW pest, which has been shown to preferably attack the maize crop. Thus, use of the judgmental sampling technique in preferably selecting high maize producing areas in Zimbabwe.

Mashonaland West and Mashonaland Central provinces were selected based on their high maize production capacity in Zimbabwe. The districts were also selected based on the same criteria of maize production within their respective provinces (Ministry of Agriculture Mechanisation and Irrigation Development, 2017). In addition to the capacity to produce maize, there must also have been documented evidence on the presence of the fall armyworm presence in these areas in the 2018-2019 cropping season. The evidence must have been from the A1 model farming community.

3.4.1 Section of Districts and Sub-Wards

Makonde district was chosen in Mashonaland West by virtue of being the highest producing district in the Province based on 2017-2018 AGRITEX production statistics (AGRITEX, 2018). The same criteria also applied to the selection of Mazowe district in Mashonaland Central province. From the list of wards within the district, the top five producing wards were selected based on production. These had to be within 40km radius from the district office. The top five wards names were put in a box and then randomly picked whilst blind folded.

Quota sampling is a combination of judgement sampling and probability-based sampling techniques. The selection of a sample is based on an assumption or previous knowledge of a certain characteristic of a target population and the proportion of the population within each category is decided. A quota of subjects to be drawn from the population is fixed and the one doing the sampling is allowed to sample that value wherever they like (Pandey & Pandey, 2015).

Quota sampling was used to determine the respective sample size for Makonde ward 9 and Mazowe ward 25 out of the predetermined sample size of 225. The quota for Makonde ward 9 was determined as 94 and that for Mazowe ward 25 as 130. Quota sampling was also further done in ward 9 as it had three distinct areas due to soil types and commonly grown crops. Sandy (sub-ward A), loamy (sub-ward B) and heavy clays (sub-ward C) with commonly grown crops being, maize and tobacco; maize and cotton; maize and soybeans respectively. These three sub-wards also receive extension advice from three different extension officers. Quota sampling was used to determine the sample size as follows; 29 respondents from sub-ward A,28 respondents from sub-ward B and 37 respondents from sub-ward C.

3.4.2 Selection of interviewees

Within the selected ward, respondents were selected from a list of maize growing farmers using the random sampling method. Respondents were household heads or any adult who was at home at the time the study was being conducted. Each potential respondent was supposed to answer yes to a set of pre-interview questions. The question enquiring about the household's maize production practices in the 2018-2019 season related to pest identification and control. They should have planted maize in the 2018-2019 season and also from the discussion shown to have shown to have used some method as they tried to control the pest. This assessment was based on the pre-interview training conducted by the interviews. The potential respondents should also have been willing to be interviewed.

3.5 Data collection procedure

Primary and secondary sources of data were used in the study. Primary sources of data included direct communication with farmers and extension officers through questionnaire-based interviews, focus group discussions and key informant interviews. Secondary data sources included journals, public electronic sources, and government departments source documents.

3.5.1 Quantitative data

A semi-quantitative questionnaire was used to collect data from the respondents. Themes of the questions focused on social-demographics, farm, and farm management characteristics, knowledge and perception of the fall armyworm, pest and pesticide management practices.

3.5.2 Qualitative data

Three key informant interviews with AGRITEX officers and one focus group discussion were used to collect qualitative data, which was used to augment quantitative data. The interviews were conducted with the aid of an interview guide adopted from a FAO training manual on fall armyworm Focus Group Discussion and Key Informant Interview Check List (FAO, 2018b). The interview guide served as a map for the path that needed to be followed by the researcher so as to obtain relevant information which was critical to answering the research questions and also augment quantitative data.

3.5.3 Pilot testing

A pilot survey was carried out in ward 9 sub-ward A using a convenience sample of 10 A1 model farmers. The purpose of the pilot test was to check for any weaknesses in the tool and then institute appropriate changes to enhance its effectiveness. This included the length of time to obtain adequate and meaningful data, and also ensure the survey tool had concept validity and reliability. This was done in the first week of April (Kumar, 2011).

3.6 Data analysis procedure

The coded responses in the questionnaire were transferred to excel first then cleaned by checking for capturing errors and analysed using SPSS v.20 at 5% level of significance as described below:

Objective 1: To determine the methods being used by smallholder farmers in controlling the fall armyworm in maize and their perceived effectiveness

Data analysis: Frequency tables and graphs were used to summarise the reported data on methods which were used by the respondents. The relationships between variables in Table 3.1 were analysed using logistic regression and where a statistically significant relationship was observed it was reported.

Objective 2: To determine chemical pesticides and the application rates being used by smallholder farmers in controlling the fall armyworm in maize.

Data analysis: Frequency tables and graphs were used to summarise the reported data on the pesticides which were used by the farmers in controlling the FAW. The application rates used by farmers were compared to the recommended application rates using their means. The relationships between variables in Table 3.1 were analysed using logistic regression and where a statistically significant relationship was observed it was reported. The allowed variation in mass or volume between the application rate used by farmers and the recommended application rate was 5% (Harvey 2012).

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Objective 3: To determine pesticide risk mitigation measures used by smallholder farmers in controlling fall armyworm.

Data analysis: Frequency tables and graphs were used to summarise the reported data on the measures taken by famers in reducing the risks associated with pesticide use in controlling the FAW. The relationships between variables in Table 3.1 were analysed using logistic regression and where a statistically significant relationship was observed it was reported.

Objective 4: To determine the factors that affect selection of fall armyworm control methods by smallholder farmers.

Data analysis: Frequency tables and graphs were used to summarise the reported data on the factors influencing the farmers, knowledge, attitudes, and practices in the selection of FAW management methods. The relationships between variables in Table 3.1 were analysed using logistic regression and where a statistically significant relationship was observed it was reported.

Qualitative data were analysed for content and the content grouped into themes. The themes were then used to augment quantitative data responses and also provided an explanation of the behaviour of the farmers in their pest and pesticide management practices.

Objective 5: To determine the factors that influence the selection and use of personal protective equipment by smallholder farmers.

Data analysis: Frequency tables and graphs were used to summarise the reported data on the factors influencing the farmers, knowledge, attitudes, and practices in the use personal protective equipment. The relationships between variables in Table 3.1 were analysed using logistic regression and where a statistically significant relationship was observed it was reported.

Qualitative data were analysed for content and the content grouped into themes. The themes were then used to augment quantitative data responses and also provided an explanation of the behaviour of the farmers in their pest and pesticide management practices.

Logistic regression model

Logistic regression is an analytical model that is used where there is a dichotomous/binary or multinomial dependent variable. Logistical regression quantifies the relationship between dichotomous dependent variable and the predictors using odds ratios (OR). The odds ratio (OR) is an indication that the odds of a success (case) outcome are equally likely for to the odds of a failure (non-case) The odds ratio has a minimum value of zero but have no upper limit. A value less than one indicate that the case is not likely to prevail under those circumstances and a value greater than one indicates a high likelihood for belonging to the group. The further the odds ratio is from one, the stronger the relationship (Allison, 2014).

Odds=P(case)/P(non-case/failure)

Odds = $(P_i / (1-P_i)$

Odds= $P_i/(1-P_i) = \exp(\beta_0 + \beta 1 x_i)$

OR=Odds of a case/Odds of a non-case

Taking the natural logarithm of both sides: $\text{Log}(P_i / (1- P_i) = (\beta 0 + \beta 1 x_i)$

Log(odds)= Logit (P_i)

Where Logit (P_i) is the natural logarithm of the odds of outcome,

The coefficients $\beta_1, \beta_2 \ldots, \beta_{p-1}$ are estimated using the maximum likelihood (ML) method.

$\text{Log}(P_i /(1- P_i) = \text{Logit}(P_i) = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_{p-1} x_{p-1}$

P_i =is the probability of an event that depends on the p-independent variables $x_1, x_2,$

$x_3 \ldots x_k$=independent variables

β_o=coefficient of the constant term

$\beta_1, \beta_2, .., \beta_{p-1}$=the coefficients of the p independent variables

Variables in the model

The model tested how the independent variables influenced the depended variables in the study and to what extend could the dependent response variable be explained by the independent variables (Table 3.1).

Table 3. 1 Variables used in the logistic regression model

Independent variables	Dependent variables
Age, gender, level of education, training on FAW identification and control	Wearing personal protective equipment
Age, gender, level of education, training on FAW identification and control	FAW control methods
Wearing personal protective equipment, age, gender, level of education, training on FAW identification and control	Feelings of discomfort

3.7 Ethical considerations

Relevant authorisation from the AGRITEX directorate, Provincial, District offices were sought before the study was conducted. Traditional leaders' permission was also sought in the relevant villages before conducting the survey. Informed consent was sought from each potential respondent before they were interviewed. All the data collected is treated with confidentiality and the views of each individual household treated equally.

3.8 Summary of methodology

The methodology used in the study combined probability and non-probability-based sampling methodologies in data collection. Quantitative and qualitative techniques were combined so as to improve the robustness of the methodology and obtain more accurate information with minimum bias. Frequency tables and graphs were used to used summarise the reported information. Logistical regression was used to test for association between variables in the questionnaire. Where a statistically significant relationship was observed it was reported as Odd Ratio, Confidence Interval, and the p value.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter presents the results of the study. Objective one sought to determine the non-chemical methods being used by smallholder farmers in controlling the fall armyworm and their perceived effectiveness. Objective two was to determine chemical pesticides and the application rates being used by smallholder farmers in controlling FAW. Objective three was to determine pesticide risk mitigation measures used by smallholder farmers as in controlling the FAW. The fourth objective was to determine the factors that affect selection of fall armyworm control methods, and use of personal protective equipment

4.2 Demographics

4.2.1 Demographic characteristics of respondents

The respondents consisted of 75% of household heads, whilst 25% were not. Respondents who were not household heads consisted mainly of spouses (13%), the rest were children, workers and relatives (Table 4.1). Most (81.6%) of respondents were male. The majority (60.4 %) of the those interviewed were in the 30 to 49-year age group, and the average age was 43 years.

The majority (99.1%) of the respondents had some level of education and this signifies a greater ability to make a well-informed decision in any given situation. Nearly half of the study population (47.6%) attained the basic level of education acceptable in Zimbabwe, which is an Ordinary level, 2.2% had a tertiary qualification and 0.4 % had Advanced Level qualification. Other farmers did not complete “O” level (20.9%), while some only completed primary level education (15.1%).

Table 4. 1 Demographic characteristics of respondents in the fall armyworm questionnaire survey (N=225)

Description of demographic variable		**Percent**
Gender	Male	81.6
	Female	18.4
Marital status	Married	92.0
	Single	4.9
	Widowed	2.7
	Divorced	0.4
Age*	20-29	9.8
	30-39	37.3
	40-49	23.1
	50-59	15.6
	60-69	10.2
	70-79	4.0
Highest level of education achieved	No formal education	0.9
	Incomplete Primary School	12.9
	Complete Primary School	15.1
	Incomplete "O" level	20.9
	Completed "O" level	47.6
	A-level	0.4
	Tertiary	2.2
Main income generating activity of HH	Farming	100.0

*Mean age 43.1±12.6

4.3 Methods used by smallholder farmers in controlling the fall armyworm and their perceived effectiveness.

4.3.1 Methods used by smallholder farmers in the control of the fall armyworm

The study showed that 76.4% of the farmers used chemical pesticides, whilst 26.7% crushed FAW larvae by hands,11.1% collected the larvae and gave to chicken (Figure 4.1). Less than 10% used other methods such as application of detergents, wood ash, ammonium nitrate fertiliser and less than 5% applied sand, sprayed a solution of dead FAW larvae, a mixture of plant extracts which include tobacco and manure. Seventy-one comma one percent (71.1%) of the respondents used only one method to control the FAW, whilst 28.9% used more than one method to control the pest.

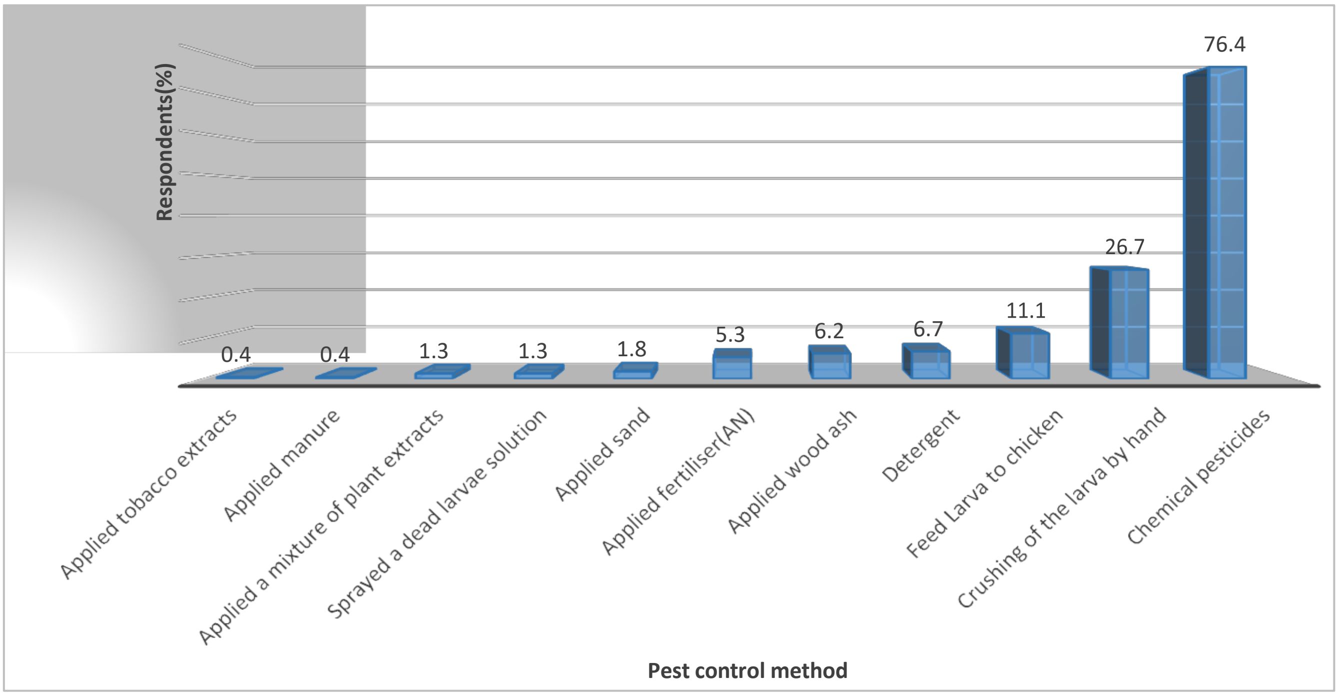

Figure 4. 1Methods used by farmers in controlling the fall armyworm (N=225).

The use of chemical pesticides in the control of FAW is gender related with a male farmer more likely to use chemical pesticides than a female farmer (OR= 2.23; 95% CI= 1.07 – 4.59; $p<0.05$). The female farmer is more likely to use the method of collecting the pest larvae and feeding to chicken than the male farmer (OR= 5.4; 95% CI= 2.26 – 13.1; $p<0.05$). The likelihood of applying detergent was shown to be related to the age of the respondent farmer (OR= 1.07; 95% CI= 1.03 – 1.12; $p<0.05$), the older they were the more likely they used detergent.

4.3.2 Perceived effectiveness of non-chemical pesticide methods by farmers

The study showed that 61.7% of the farmers who hand crushed larvae as a method of FAW control perceived that the method was effective (Table 4.2). Fifty percent of all the methods were reported as predominantly mildly effective whilst the other 50% was reported to be effective.

Table 4. 2 Perceived effectiveness of non-chemical pesticide methods used by farmers to control fall armyworm in maize

FAW control method	Effective (%)	Mildly effective (%)	Not effective (%)	Number of farmers*
Crushing of the larvae by hand	61.7	31.6	6.7	60
Hand pick and feed to chicken	40	52	8	25
Applied detergent	13.3	46.7	40	15
Applied wood ash	100	-	-	14
Applied Ammonium Nitrate fertiliser	75	25	-	12
Applied sand	-	100	-	4
Sprayed a dead larvae solution	100	-	-	3
Applied a mixture of plant extracts	-	100	-	3
Applied manure	100	-	-	1
Applied tobacco extracts	-	100	-	1

*N signifies the number of farmers who used that particular method of FAW control

4.4 Chemical pesticides and their application rates used by maize smallholder farmers in managing the fall armyworm

4.4.1 Chemical pesticides used by farmers in controlling the fall armyworm

The study showed that 35 % of the active ingredients used by the farmers are registered for the control of the FAW in Zimbabwe (Table 4.5). Twenty percent (20%) are registered for use in other countries, Kenya (5%), South Africa (5%) and Brazil (10%). The remaining 45% are not registered for control of FAW neither do they control any of the lepidopteran species pests. Lambda cyhalothrin (32%), followed by Emmamectin Benzoate (13.8%) and Carbaryl (9.8%) were reported as the commonly used active ingredients (Table 4.3). Ten percent of active ingredients used by farmers are highly restricted, whilst fifteen percent are restricted pesticides (Table 4.4). Forty percent belong to not restricted level 1(more toxic than level 2) and the rest (40%) are belong to the class of not restricted level 2(very low toxicity).

Farmers who were trained on identification and control of the FAW by extension were more likely to use chemical pesticides than those who did not receive any training (OR= 2.26; 95% CI = 1.21 – 4.23; $p<0.05$). Male farmers were more likely to use chemical pesticides than female farmers (OR: 2.23.

95% CI: 1.07 – 4.59: p<0.05). There was no significant relationship observed between age and level of education as determining factors in the use of chemical pesticides.

Table 4. 3 Synthetic pesticides used to control the fall armyworm in maize (N = 225)

Active Ingredient	**Trade name/ Formulation**	**Registration of active ingredient against fall armyworm in Zimbabwe or other countries**	**Classification of active ingredient by use**	**Respondents who used the pesticide [Frequency (percent)]**
Lambda cyhalothrin	Lambda cyhalothrin 5EC	Zimbabwe	Insecticide	72(32)
Carbaryl	Carbaryl	Zimbabwe	Insecticide	22(9.8)
Emmamectin Benzoate	Macten/ Nemesis/ Super Dash	Zimbabwe	Insecticide	31(13.8)
Acephate	Acephate 75SP	Kenya	Insecticide	12(5.3)
Lambda cyhalothrin and Acetamiprid	Blast/Bullet	Zimbabwe	Insecticide	6(2.6)
Deltamethrin	Ecoterex 0.5GR	Zimbabwe	Insecticide	3(1.3)
Flubendiamide	Belt	Zimbabwe	Insecticide	3(1.3)
Deltamethrin	Decis forte/Combat	Brazil	Insecticide	5(2.2)
Emmamectin Benzoate and Acetamiprid	Blast Super	Zimbabwe	Insecticide	2(0.9)
Cartap hydrochloride	Cartap hydrochlor	South Africa	Insecticide	1(0.4)
Imidacloprid	Imidachloprid 200SL	Brazil	Insecticide	1(0.4)
Methamidophos	Methamidophos 500SL	Deregistered by GOZ	Insecticide	8(3.6)
Imidacloprid and Beta-cyfluthrin	Thunder	None	Insecticide	4(1.8)
Mancozeb	Dithane M45	No registration	Fungicide	2(0.9)
Dimethoate	Rogor	No registration	Insecticide	2(0.9)
Fenvalerate	Fenkill	No registration	Insecticide	2(0.9)
Monocrotophos	Deregistered by GOZ	Deregistered by GOZ	Insecticide	2(0.9)
Trichlofon	Dipterex	None	Insecticide	1(0.4)
Atrazine	Atrazine 500SC	None	Herbicide	1(0.4)
Fipronil	Fipronil 20SC	None	Insecticide	1(0.4)

(Constructed from data obtained from Abrahams *et al.*, 2017; IRAC South Africa, 2018; ZAOISTech, 2018)

Table 4. 4 Hazard classification of product formulations used by farmers

Active Ingredient	**Chemical group**	**Acute Oral LD_{50} of Product**	**Hazard classification / use restriction**	**Frequency (percent)**
Monocrotophos	Organophosphate	1-100	Extremely poisonous/ highly restricted	2(0.9)
Methamidophos	Organophosphate	1-100	Extremely poisonous/ highly restricted	8(3.6)
Dimethoate	Organophosphate	101-500	Dangerous poison/ restricted use	2(0.9)
Acephate	Organophosphate	101-500	Dangerous poison/ restricted use	12(5.3)
Lambda cyhalothrin	Pyrethroid	101-500	Dangerous poison/ restricted use	72(32)
Fenvalerate	Pyrethroid	501-2000	Poison/unrestricted	2(0.9)
Deltamethrin	Pyrethroid	501-2000	Poison/unrestricted	5(2.2)
Lambda cyhalothrin and Acetamiprid	Pyrethroid and Neonicotinoid	501-2000	Poison/unrestricted	6(2.6)
Beta-cyfluthrin and Imidacloprid	Pyrethroid and Neonicotinoid	501-2000	Poison/unrestricted	4(1.8)
Cartap hydrochloride	Nereiston Analogue	501-2000	Poison/unrestricted	1(0.4)
Carbaryl	Carbamate	501-2000	Poison/unrestricted	22(9.8)
Trichlofon	Organophosphate	501-2000	Poison/unrestricted	1(0.4)
Deltamethrin and Pirimiphos methyl	Pyrethroid and Organophosphate	<2000	Harmful if swallowed/ unrestricted	3(1.3)
Emmamectin Benzoate and Acetamiprid	Avermectin and Neonicotinoid	<2000	Harmful if swallowed/ unrestricted	2(0.9)
Emmamectin Benzoate	Avermectin	<2000	Harmful if swallowed/ unrestricted	31(13.8)
Flubendiamide	Diamide	<2000	Harmful if swallowed/ unrestricted	3(1.3)
Imidacloprid	Neonicotinoid	<2000	Harmful if swallowed/ unrestricted	1(0.4)
Mancozeb	Dithiocarbamate	<2000	Harmful if swallowed/ unrestricted	2(0.9)
Atrazine	Triazine	<2000	Harmful if swallowed/ unrestricted	1(0.4)

4.4.2 Fall armyworm pesticides application rates by farmers

Twenty two percent of the insecticides used by the farmers were applied following the manufactures recommended application. The remaining 77.8 % were either under applied or over applied, Carbaryl and Acephate were underweighted whilst Cartap hydrochloride was overweighed (Table 4.5 and Table 4.6).

Table 4. 5 Comparison between mass of pesticides applied by farmers to 15 litres water and recommended application rates for controlling fall armyworm (N=47).

Active ingredient	**Trade name**	**Weight of pesticide in grams (measurement is done with scale by student)**	**Weight of pesticide in grams (measurement by farmers using fertiliser measuring cups)**	**Recommended quantity per 15 litres Knapsack**
Carbaryl	Carbaryl 85WP	19.0±1.0	52±28.3	141
Acephate	Acephate 75SP	32.0±1.6	37.3±14.9	12
Cartap Hydrochloride	Cartap Hydrochloride 200 SP	67.2±3.4	60±3	60
Emmamectin Benzoate	Macten	24.5±10.7	30±14	23

Table 4. 6 Comparison between volume of pesticides applied by farmers to 15 litres water and recommended application rates for controlling fall armyworm (N=91).

Active ingredient	**Trade name**	**The volume of pesticide in ml (measurement by farmers with a fertiliser measuring cup)**	**Recommended quantity per 15 litres Knapsack**
Emmamectin benzoate (64g/l) and Acetamiprid(48g/l)	Nemesis	33.3± 6.6	18-45
Emmamectin benzoate(50g/l) and Acetamiprid (20g/l)	Super dash	30±1.5	18
Flubendiamide	Belt	45±21.2	16
Lambda cyhalothrin	Lambda cyhalothrin	26.3±11.5	15
Lambda cyhalothrin and Acetamiprid	Blast/Bullet	33.3±5.2	30

4.4.3 Source of information on application rates used by farmers

The majority (49.3%) of the respondents reported using the label as the main source of information on the application rates they used. Less than 15% used other sources of information for the application rates notably advice from extension, friends, and knowledge from tobacco production.

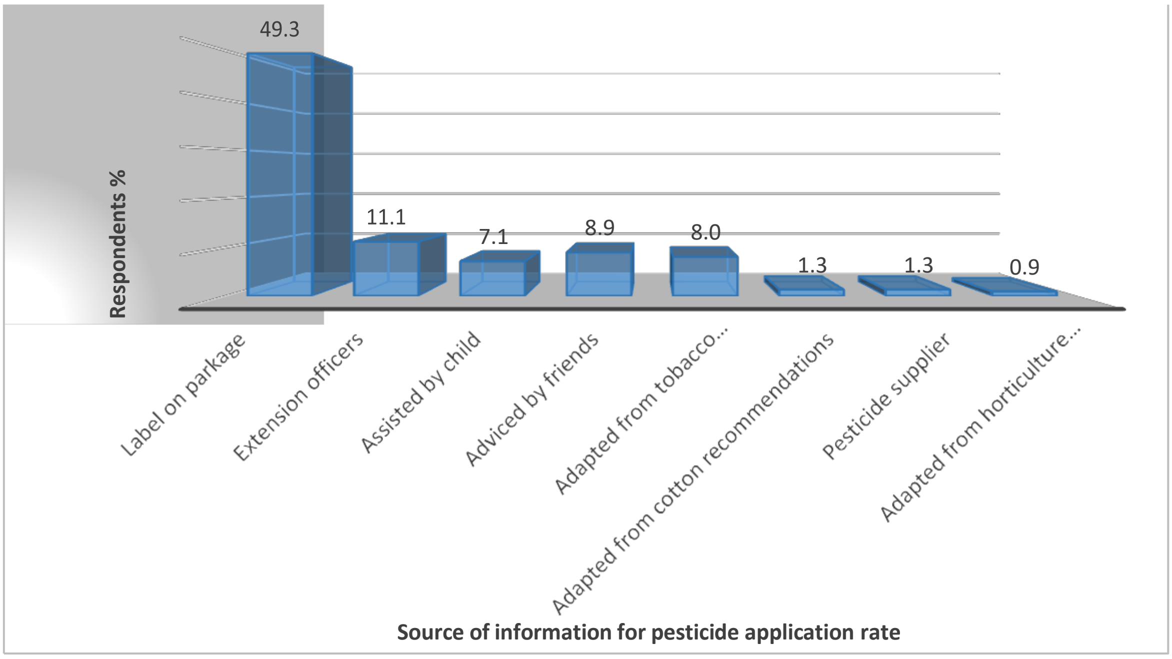

Figure 4. 2 Source of information on pesticide application rate used by farmers

4.4.4 Farmers perception on pesticides effectiveness

Forty-seven comma six percent (47.6%) of the respondents perceived that chemical pesticides were effective, whilst 12% perceived that they were not effective (Figure 4.3).

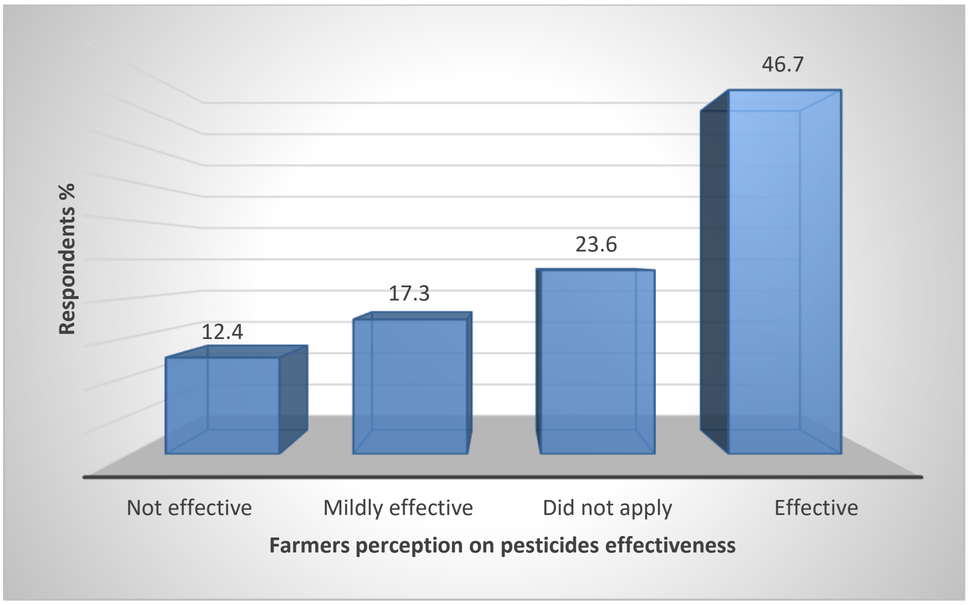

Figure 4. 3 Farmers perceptions on pesticides effectiveness

4.5 Smallholder farmers pesticide risk mitigation measures in fall armyworm control

4.5.1 Personal Protective Equipment worn by farmers during preparation and application of pesticides

More than half (53.3%) of the farmers stated that they wore coveralls and gumboots (52.4%) when mixing and spraying pesticides in the control of FAW. Less than 21 % wore additional recommended PPE. Less than 16 % of the farmers used their own non-standard PPE which included wearing a cloth on the mouth and wearing a facemask, wearing latex gloves and putting on a raincoat in addition to coveralls. Twenty two percent (22%) of the respondents did not wear special clothes during the preparation and application of pesticides.

Farmers who did not receive any training by extension were more likely to have worn nothing special when spraying chemical pesticides than those who were trained (OR=4.8; 95% CI= 1.6 to 14.4; $p<0.05$). The more time spent in school by the farmers the less likely they were to use ordinary clothes when spraying instead of PPE (OR= 2.6; 95% CI= 1.15 – 5.9; $p<0.05$).

Table 4. 7 Recommended personal protective equipment worn by farmers during preparation and spraying of pesticides

Personal Protective Equipment	**Purpose of equipment**	**Percent**
Overalls and work suit	Prevention of dermal pesticide exposure	53.3
Gumboots	Prevention of dermal pesticide exposure	52.4
Rubber gloves	Prevention of dermal pesticide exposure through hands	20.9
Respirator with cartridges	Prevention of pesticide exposure through oral ingestion and inhalation	20.0
Googles	Prevention of pesticide exposure through eyes	8.4
Hat	Prevention of dermal pesticide exposure through the head and face	17.8
Trousers	Prevention of dermal pesticide exposure	8.9
Long-sleeved shirt	Prevention of dermal pesticide exposure	1.8

Table 4. 8 None-standard personal protective equipment worn by farmers during preparation and spraying of pesticides

Personal Protective Equipment	**Purpose of equipment**	**Percent**
Raincoat	Prevention of dermal pesticide exposure	15.6
Cloth on mouth	Prevention of pesticide exposure through oral ingestion and inhalation	11.0
Facemask	Prevention of pesticide exposure through oral ingestion and inhalation	8.0
Latex	Prevention of dermal pesticide exposure through hands	4.4

4.5.2 Discomfort after spraying chemical pesticides to control fall armyworm

Fifty four percent (54%) of the farmers did not feel any discomfort after spraying pesticides in the control of FAW. Farmers who wore coveralls were less likely to report feelings of discomfort after spraying chemical pesticides to control FAW than those who did not wear coveralls (OR= 3.2; 95% CI=1.8 – 5.8; $p<0.05$).

4.6 Factors affecting selection of fall armyworm control methods, and use of personal protective equipment.

4.6.1 Sources of information on fall armyworm identification and control by smallholder farmers

Most (58.2%) of the farmers received the skills to identify and control FAW from government extension officers either directly from the extension and also through field day demonstration. Less than 20% attributed their knowledge being from field day demonstration and also pesticide suppliers. Other farmers attributed their knowledge of the pest to farmer friends (27.6%), radio (15.6%) and TV (3.6%). Few (17.7%) of the farmers used a combination of sources for information on identification and control of the FAW, whilst the majority (82.2%) relied mostly on one source of information.

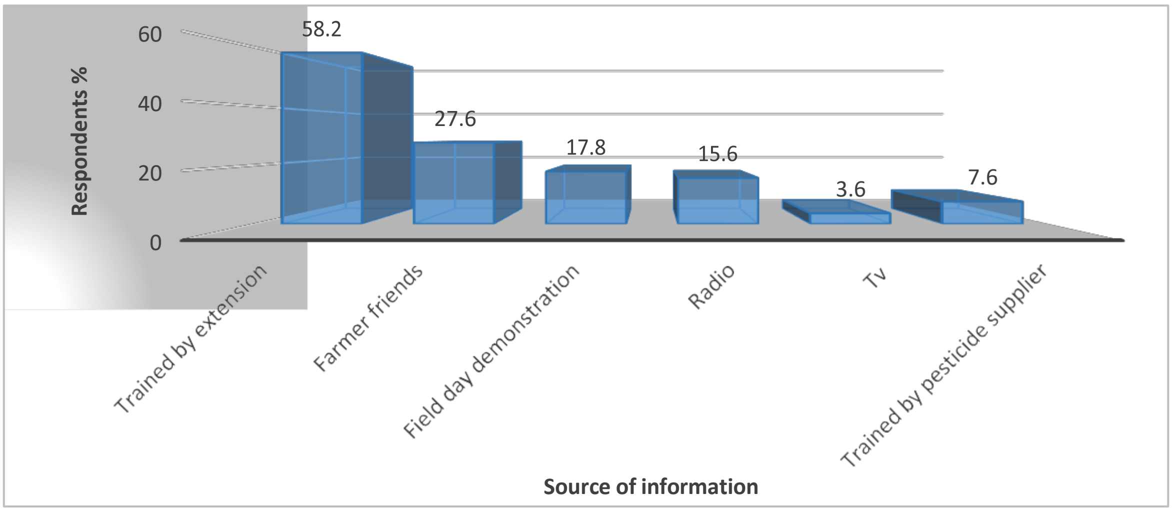

Figure 4. 4 Main sources of information on fall armyworm identification and control by farmers

4.6.2 Factors affecting selection of fall armyworm control methods by smallholder farmers

The older the respondents the more likely they were to use detergents in controlling FAW (OR= 1.0; 95% CI=1.03 – 1.12; $p<0.05$) Table 4.10. Those trained by extension officers in FAW identification and control were more likely to use chemical pesticides and wear personal protective equipment (PPE) than those who were not trained. Those who did not wear any coveralls were more likely to report discomfort after pesticide application than those who wore coveralls (OR= 3.2; 95% CI=1.8 – 5.8; $p<0.05$).

Table 4. 9 Summary of statistically significant relationships between independent and dependent variables in the logistical regression model

Independent variable	**Dependent variable**	**EXP(B)**	**95% C.I.for EXP(B)**	
			Lower	**Upper**
Gender (Male)	Pesticide application to control FAW	2.22	1.07	4.59
Gender (Female)	Collecting FAW larvae and feeding chicken	5.41	2.26	13.1
Age	Applying detergent to control FAW	1.07	1.03	1.12
Training on FAW identification and control by extension (TRUE)	Pesticide application to control FAW	2.26	1.21	4.23
Trained on FAW identification and control by extension (FALSE)	Nothing special worn when spraying PPE	4.8	1.6	14.4
Level of education secondary	Nothing special worn when spraying PPE	2.6	1.15	5.9
Wearing coveralls as PPE (FALSE)	Feelings of discomfort after spraying chemical pesticides to control FAW	3.2	1.8	5.8

CHAPTER 5: DISCUSSION

5.1 Discussion

The respondents consisted of 75% of households' heads, whilst 25% were not which implies the information collected is a significant representative of the characteristics of the community studied. The relationship of the respondent to the household head has a bearing on the accuracy of the information provided by the respondent (Hubrich & Wittwer, 2014)**.** The closer they are the more accurate then information. Respondents who were not household heads consisted mainly of spouses (13%), the rest were children, employee's and relatives. Spouse's though not household heads play a pivotal in the decision-making process at household level hence provide information which is equally as good as the one from the household head. This results in an 88% contribution to the influence of the decision making at the household level by all respondents in the study**.**

Hand crushing of FAW larvae by farmers was reported as the second most common method of FAW in the study area (Figure 4.1). This method has also been used in the Americas where the pest originated from, it been reported to have been used in other African countries Zambia, Kenya, Ethiopia, Ghana, and Namibia (FAO, 2018a). It's also one of the methods recommended for an Integrated Pest Management strategy for the control of the FAW (Mulilamitti, 2017; Prasanna et al., 2018) by smallholder farmers. Application of sand, ash, detergent, tobacco extracts, manure, fertiliser are also not new methods by smallholder farmers in Africa and have also been used in the Americas (FAO, 2018a; Kumela et al., 2018; Rwomushana et al., 2018). The feeding of hand caught larvae to chicken and spraying a mixture of dead larvae as control methods has not been reported in other countries except in Zimbabwe (Mulilamitti, 2017). Hand crushing of larvae was perceived as predominantly effective by the farmers (Table 4.2). In a study in Namibia the majority (67%) perceived that hand crushing was somewhat successful, which is equivalent to mildly effective in this study (FAO, 2018a). The majority of the respondents (76% in Ghana and 61.9% in Zambia) reported hand-crushing of larvae as ineffective (Rwomushana et al., 2018). Further studies are required to establish the actual costs and benefits of crushing by hand in terms of FAW damage, yield and the cost-benefit related to this method.

All the respondents who used ash perceived that the method was effective, this has also been observed in other studies in Ghana (58.3%) and Zambia (53.6%) (Rwomushana et al., 2018). In Namibia, less than 10% perceived that the use of ash in controlling the FAW is effective whilst

65% reported that the method was not effective at all (FAO, 2018a). The majority (75%) of those who used fertiliser perceived the method as effective, this effectiveness can be attributed to the hygroscopic nature of the fertiliser. When the FAW larvae get in contact with the fertiliser, it gets dehydrated and this results in the death of the pest. Fertiliser is also slightly corrosive and this can also cause damage to the outer layer of the FAW larvae leading to its death (Loukil et., 2015). Some of the respondents reported the wilting and death of the maize plant if too much of the fertiliser was applied. This phytotoxicity can be attributed to the partially corrosive nature of fertiliser. The use of detergents and fertiliser in controlling the FAW larvae is not sustainable and practical due to the high cost of procuring these products compared to the monetary value of maize when sold. Less than 5% of the farmers used plant extracts and they reported them as mildly effective. The ability of these extracts to control the FAW is dependent on the inherent characteristics of the plant to be toxic to the *lepidopteran spp*.

Farmers preferably (76.4%) used chemical pesticides in the management of FAW (Figure 4.1). The preference for chemical pesticides by smallholder maize farmers in the control of FAW in Zimbabwe is not new in the region. Studies in sub-Saharan countries have also shown this trend with 53% using synthetic pesticides in Ghana and 43% in Zambia, Kenya (48.1%) and Ethiopia (48.3%) (Kumela et al., 2018; Rwomushana et al., 2018). A study by FAO, 2018 in Namibia also showed the preference for pesticide use by farmers, if they are accessible. The main reasons for the preference of synthetic pesticides are the lack of information of other sustainable methods of FAW control, perceived effectiveness of the method and ease of accessibility of the products (Abrahams et al., 2017). In as much as chemical pesticides were commonly used, they were also used together with non-chemical methods. The combining of chemical and non-chemical methods in the management of the FAW was also reported in Ethiopia, Kenya, Zambia, and Ghana (Kumela et al., 2018; Rwomushana et al., 2018).

The use of active ingredients not registered for the pest as 45% of the total active ingredients reported by farmers in the study signifies great desperation by the farmers. Farmers reported to have used fungicides, herbicides and highly toxic insecticides that were banned in Zimbabwe such as Methamidophos and Monocrotophos. This also exemplifies some of the public health risks the farmers were exposed to as they tried to control the FAW (Table 4.3 and 4.4). In Zambia, Monocrotophos was reported as one of the commonly used active ingredients regardless of its toxicity (Rwomushana et al., 2018). The commonly used active ingredients were reported as Lambda cyhalothrin (32%), followed by Emmamectin Benzoate (13.8%) and Carbaryl (9.8%). They were obtained from pesticide retailers and the Command Agriculture government inputs scheme. This made farmers to quickly get access to them and also information concerning their use. The areas studied are commonly tobacco growing areas and so farmers used Lambda and Carbaryl from their tobacco crop. Carbaryl, Lambda cyhalothrin, Acetamiprid, Fenvalerate, and Fipronil have also been shown to have been used by other smallholder farmers in Zimbabwe in the Zambezi valley flood plains (Chimweta et al., 2019). Resistance to the pesticides Lambda cyhalothrin, Carbaryl and Fenvalerate by the fall armyworm has been reported in America and these were some of the most commonly used insecticides in the study areas (Horikoshi et al., 2016; Yu, 1991). These have also been used in other countries within sub-Saharan Africa region, which presents a potential resistance development time bomb that needs to be quickly mitigated against (Rwomushana et al., 2018).

There are no biological pesticides (bio-pesticide) registered for the control of FAW in Zimbabwe. However, there are bio-pesticides that have been registered for the control of FAW in Kenya, South Africa, and the same products are also used in Zimbabwe for other insect pests (IRAC South Africa, 2018). The lack of use of these products for FAW control by farmers is can be interpreted as non-use of these products for control of insects other than FAW. This is an indicator of the great reliance on chemical pesticides by the smallholder farmers in Zimbabwe. Bio-pesticide use in Ghana was linked to advice from Extension services advice, backed by legislation information on the registration status of the products (Rwomushana et al., 2018).

Farmers reported using fertiliser measuring cups for weighing granule and powder-based formulations, however, these cups are calibrated for liquids and certain fertiliser formulations. The cups were not calibrated to measure any of the powder and granule-based pesticides which were used by farmers in the study. This resulted in a deviation between the perceived weight reported by the farmers and the actual weight measured using a calibrated scale (Table 4.5). Carbaryl, Acephate, and Emmamectin Benzoate were under weighed, whilst Cartap Hydrochloride was overweighed. The actual weighed quantity of the powder and granules were different from the recommended rate of application rates except for Macten (Emmamectin Benzoate). Carbaryl was under applied whilst Acephate and Cartap Hydrochloride were overapplied. The measured quantity for liquid formulations used by farmers was above the recommended application rate except for Nemesis (Emmamectin Benzoate) (Table 4.6). The majority (66.7%) of the active ingredients were applied using application rates above the recommended quantity and only 22.2% used the recommended rate. Literature explains the use of application rates above the recommended rates by farmers as a sign of the perceived ineffectiveness of the chemical pesticides (Sisay et al., 2019). Farmers are then ‘’forced’’ to use higher dosage so that they obtain the required efficacy.

Data from the study showed that 49.5% of the farmers used information from labels for the application rates (Figure 4.2), whilst the remainder used various sources of information such as extension officers (11.1%) and advice from friends(8.9%). Failure to adhere to recommended application rates may also be taken to mean the inability to properly understand the labels. Failure to properly read and understand labels by smallholder farmers has been reported in a study in Ethiopia, with only 8% of the study population reading and understanding labels correctly (Mengistie et al., 2015). There are several problems that are encountered by farmers when they do adhere to the recommended rates and these include ; resistance to pesticides quickly develops as a result of selection pressure by the overdose insecticide; farmers are exposed to health risks associated with using a rate above the recommended one; phytotoxicity; pesticide residues in food; environmental contamination. A lower dose results in reduced efficacy of the insecticide and crop damage by the pest. Lower rates also increase the likelihood of resistance development.

Forty-six comma seven percent (46.7%) of the farmers reported that the controlling FAW with chemical pesticides was effective (Table 4.7). Effectiveness of chemical pesticides application can be described in two ways, the time it takes to see the effect on the target pest and its ability to be applied over a large piece of the area within a short space of time. However, the cost of chemical pesticides is not always friendly to smallholder farmers and they do wear the full recommended PPE posing a risk to their health (Zinyemba et al., 2018). The perception that chemical pesticides are effective in controlling FAW by smallholder farmers has been reported in the literature and also disputed in the literature. In a study in Ethiopia (46%) of respondents reported that chemical spraying was effective, in Ghana (91.2%) and Zambia (97%) farmers also reported the same. Whilst in a study in Kenya 60% reported that the use of chemical pesticides was not effective (Kumela et al., 2018; Rwomushana et al., 2018). Thus, effectiveness should be interpreted within the context in which the study was conducted and the interpretation of the phrase effectiveness. The perception of the effectiveness of using chemical pesticides method’s in controlling FAW was associated with obtaining information on the application rates from the pesticide label and also extension advice. This shows that farmers relied on information from the label and also from extension in the application rates they used on pesticides, even though they did not follow this recommendation.

Farmers in the study did not wear the full recommended PPE, just above half of the population wore only coveralls (53%) and gumboots (52%), with less than 15% wearing additional recommended PPE (Table 4.8 and 4.9). Slightly above half (54%) of the respondents reported no feelings of discomfort after using chemical pesticides in controlling FAW (Figure 5.2). Failure to wear the complete recommended PPE exposed them to health risks associated with pesticide exposure. The health problems include headaches, dizziness, nausea, skin and eye irritation in the short term and cancer's, reproductive disorders, immunotoxicity and endocrine disruption in the long term(Magauzi et al., 2011).Studies in Zambia and Ghana in the utilisation of PPE by smallholders during the control of the FAW also showed similar results, with 53.3% in Ghana and 42.7% in PPE Zambia not using proper PPE(Rwomushana et al., 2018). Low utilisation of PPE is a serious challenge among many smallholder farmers in Africa and in particular Zimbabwe (Zimba & Zimudzi, 2016; Sharifzadeh et al., 2018). It also presents one of the greatest challenges when it comes to pesticide risk management by pesticide regulators (FAO, 2016; Zinyemba et al., 2018). Some of the challenges that prevent farmers from using the full PPE is because of the prohibitive prices of the kit and also the hot environmental climatic conditions in which the sub-Saharan famers are exposed (Henry & Feola, 2013). The majority (54.2%) of the respondents used restricted pesticides and highly restricted pesticides and without using the full recommended PPE they are highly exposed to pesticide exposure related health risks. Thus, the need to promote less toxic chemical pesticides, bio-pesticides and implement an Integrated Pest Management system for the control of FAW especially bio-pesticides and (Khan & Damalas, 2015). Wearing of PPE during pesticide preparation and spraying is the last risk mitigation strategy that should be used in pesticide risk management (FAO, 2016).

Farmers also reported to the practice of putting a cloth on the mouth, using a face mask without cartridge and using latex gloves (Table 4.9). Farmers perceive that the use of these will offer adequate protection from pesticide exposure. However, these are not manufactured from the recommended material to offer adequate protection. They actually increase pesticide exposure as farmers do not take necessary protect perceiving that they are adequately protected whilst they are not. Only 22% of the farmers stated that they nothing specific for spraying and these are greatly exposed to pesticide related risks together with their families as they use the same clothes at home.

The study identified Extension services, pesticide retailers, TV, radio and farmer friends as key determinants of factors that influenced farmer's selection of FAW control methods and use of personal protective equipment. In a study in Ghana, the use of bio-pesticides by smallholder farmers in the control of FAW was as a result of advice from Extension services, highlighting their crucial role in the sustainable management of the pest (Rwomushana et al., 2018). Whilst in Namibia only 40 percent of the farmers were reported to have carried out interventions to reduce the impact on maize by FAW partly because a high proportion of both extension and farmers did not know what to do (FAO, 2018a). Media, extension sources were also reported to have been used as the key sources of information on FAW identification and management in Ethiopia and Kenya (Kumela et al., 2018).

Farmers who were trained on FAW identification and control by extension were 2.26 times more likely to use chemical pesticides than those not trained (Table 4.4). This shows the great influence extension has on the methods of controlling FAW being used by farmers. The same observation was also reported in Ghana where the number of farmers who used of bio-pesticides increased significantly by 37.1 % between 2017 and 2018 as a result of the advice from extension and promotion by government policies (Rwomushana et al., 2018). Farmers who did not receive any training by extension were 4.8 times more likely to have worn nothing special when spraying chemical pesticides than those who were trained by extension. Thus, an extension is a key factor in the selection of FAW management practices by farmers and the appropriate risk mitigation measures. Farmers who wore coveralls, rubber gloves, gumboots, respirator are 3.2 times less likely to report feelings of discomfort compared to those who did not. This confirms the need to continuously encourage farmers to wear the recommended PPE and also the need to promote less toxic chemical pesticides. Farmers who attended secondary school were shown to be 2.6 times less likely to spray using ordinary clothes than those who only attended primary school (Table 4.9).

The relationship between gender and chemical pesticides application revealed that male farmers were 2.23 times more likely to use chemical pesticides than female farmers in the study (Table 4.9). Pesticide application is normally the responsibility of the male and so they are likely to choose it as means ensuring food security for the family (Oesterlund et al., 2014). Even if the household head is a female the male figure at the household is most likely to be responsible for spraying than the female. The preference for pesticide application by male farmers than female farmers was also reported in Ghana and Zambia (Rwomushana et al., 2018). Gender also had an influence on the method of collecting FAW larvae and feeding to chicken with female farmers being 5.4 times more likely to use this method than their male counterparts. Females are more likely to spent time in the field than other than male farmers doing other activities which are not related to pesticides spraying. This gives them the opportunity and time to collect FAW larvae and later on feed to chicken as the responsibility of keeping chickens at home is associated with the female gender. Female farmers were also shown to predominantly use agronomic practices in the control of FAW in Ghana than their male counterparts.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Smallholder farmers mainly used chemical pesticides (76.4%), crushing of larvae by hand (26.7%), feeding larvae caught to chicken (11.1%) as methods to control the FAW. Applying chemical pesticides was perceived as effective by 46.7% of the respondents, crushing of larvae by hand was perceived as effective by 61.7% of respondents. Hand picking of larvae and feeding to chickens was perceived as effective by 40% of the respondents in the study.

The most commonly used chemical pesticides were Lambda cyhalothrin (32%), Emmamectin Benzoate (23.6%), Carbaryl (9.8%) and Acephate (5.3%). Only two out of nine registered active ingredients used by the farmers were applied while adhering to the recommended application rates.

Farmers wore coveralls, gumboots, rubber gloves, googles, respirators, raincoat, hat, latex gloves, facemask and a cloth on the mouth so as reduce the risk of pesticide exposure. Fifty three percent (53%) of the farmers wore the coveralls, whilst fifty two percent (52%) wore gumboots and less than 15% wore additional recommended PPE as pesticide risk mitigation measures.

Training from government extension, gender, age and level of education were identified as important factors in the determination of FAW control methods and use of PPE by smallholder farmers.

6.2 Recommendations

There is a need to enhance awareness raising especially focusing on using non-chemical pesticides for controlling the fall armyworm which includes a sustainable IPM approach. The country also needs an IPM policy so as to fully harness all possible methods available globally on the management of FAW sustainably. Reliance on chemical pesticides is not sustainable and has negative implications on human health and the environment especially considering the fact that smallholder farmers are normally resource constraint and do not wear the recommended PPE.

Efficacy studies of bio-pesticides and other non-chemical based methods that have been successful in the control of fall armyworm in other countries should also be conducted in Zimbabwe. This will ensure farmers in Zimbabwe have access to products with applications rates that are efficacious in Zimbabwe. To date, none of these studies have been done in Zimbabwe to warranty registration. In addition to these research-based efficacy studies, smallholder managed demonstration plots mimicking these studies should be done so that they have a practical knowledge of these products in FAW control.

Whilst these efficacy studies are being conducted these products must be granted temporary registration status with guidance from data from countries with similar climatic conditions to Zimbabwe.

Government inputs programmes must include these bio-pesticides in the list of products being given to farmers once they have been registered in Zimbabwe. The current government inputs programmes must implement a pesticide rotation scheme based on the mode of action of the active ingredients. This will aid in reducing the likelihood of resistance developing by the FAW. The pesticide labels must include application rates for 15 litre and 16 litre knapsack sprayers as these are the ones commonly used by smallholder farmers. This reduces the likelihood of failure to interpret the application rates when the farmer is applying the pesticide. It must also be made mandatory for all pesticides containers to include appropriate measuring apparatus so as to reduce the use of inappropriate measurements.

There is a great need to promote the use of products that belong to the non-restriction pesticides category as these require minimum PPE during application. The study revealed also the need for continuous lifelong learning by farmers on so that they at least wear the basic PPE so that they protect themselves and reduce the possibility of the effects of exposure to pesticides. However, promoting the use of PPE is the least recommended method of reducing pesticide exposure and the most recommended is the use of less toxic pesticides (FAO, 2016). Continuous training of farmers on the various FAW control methods should not focus only on the use chemical pesticides but on IPM.

Radio and TV programs should also be designed in a manner that ensures correct and up to date information is disseminated to farmers. The pesticide companies also need to be monitored effectively so that they provide information that is true to farmers for sustainable FAW control.

This also goes to train them on other sustainable FAW control methods using extension officers such as the use of botanical products which can be homegrown using plants such as *Aloe Vera*. The country also needs an IPM policy so as to full harness all possible methods available globally on the management of the FAW sustainably.

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