EMERGING AND NEW PESTS UNDER CLIMATE CHANGE IN LIMPOPO PROVINCE, SOUTH AFRICA

by

MUTONDWA MASINDI PHOPHI

214578659

A thesis Submitted in Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY IN CROP SCIENCE

Crop Science

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

South Africa

2018

PREFACE

The work described in this dissertation was carried out in the University of KwaZulu-Natal, School of Agricultural, Earth and Environmental Sciences from April 2016 to December 2017 under the supervision of Professor Paramu Mafongoya.

Signed ______________________________________

Mutondwa Masindi Phophi

Date ______________________________________

DECLARATION

1. The research reported in this dissertation, except where otherwise indicated or acknowledged is my original work.
2. This dissertation has not been submitted for any degree examination at any other university.
3. This dissertation does not contain other person's data, pictures, graphs or other information unless specifically acknowledged as being source from other researchers. Where other written sources have been quoted, then:
    a. Their words have been re-written but the general information attributed to them has been referenced.
    b. Where their exact words have been used, then their writing has been placed in italics and inside the quotation marks and referenced.
4. This dissertation does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the sources being detailed in the dissertation and in the reference sections.

Signed________________________________ Date________________________

Mutondwa Masindi Phophi

As the supervisor to the candidate, I agree to the submission of this dissertation

Signed ________________________________

Professor Paramu Mafongoya

Date____________________________________

DEDICATION

To my mother Dr Lufuno Phophi and all her siblings, my son Orisedza Rivhadinda, and all my half sisters and brothers.

ACKNOWLEDGEMENTS

I would like to send special acknowledgements to my supervisor Professor Paramu Mafongoya. Thank you for all the time, knowledge, and support throughout the whole study. Without your supervision, all these would still be a dream to me. My sincere acknowledgements to Dr Obert Jiri for all your assistance in this study. My sincere gratitude to my mother Dr Lufuno Phophi for all her support throughout this study.

My acknowledgments to all staff from Limpopo Department of Agriculture for making my research a success through linking me with the farmers. I appreciate the farmers for their dedicated time in this whole study. I would also like to thank all my enumerators especially Ngwenya Thanyani for making my work a success. Special thanks to my colleagues for the support you showed me in times of need of assistance.

My acknowledgements to NRF and UKZN for this making this study possible through their fundings.

Lastly, I would love to thank the Almighty God for all the grace thus far.

ABSTRACT

Vegetable production is constrained by pests such as weeds, insects and diseases. The damage caused by pests and diseases can be highly exacerbated by climatic changes and variability. Poor agricultural practices play a role in increasing greenhouse gas emissions which contribute to climate change. Climatic factors such as increased temperature, increased carbon dioxide levels and erratic rainfall are responsible for influencing pest distributions, pest migration and increased pest population. Distribution and migration of pests can also result from globalization, trade and movement of people. Poor biosecurity and phytosanitary measures are also involved in bringing new pests in countries. This study was conducted in Limpopo Province in four municipalities of Vhembe District (Mutale, Musina, Makhado and Thulamela). Quantitative and qualitative techniques were used in data collection. Data was collected through questionnaire surveys, focus groups discussions and key informants. Farmers were randomly selected from a list provided by extension officers in each municipality. Three focus groups were conducted in each municipality consisting of seven women, seven men and a combined group of seven men and women. Statistical Package for Social Sciences (SPSS) was used to compare mean differences between different variables. Means and significant differences between means were declared at $P \leq 0.05$. The aim of this study was to evaluate the presence of new and emerging pests in Limpopo Province. The major objectives of the study were to evaluate farmer's perception on climate change and new and emerging pests, to determine the control measures used by farmers to manage vegetable insect pests, to evaluate the role of institutions on insect pest management, and to determine new and emerging pests in the district. Results of the study indicated that long dry spells, late rainfall and warmer winters were major indicators of climate change in Limpopo Province. Famers in all municipalities perceived aphids as major problematic insect pests to vegetables and were not significantly different from each other ($P > 0.05$). The highest percentage of aphid prevalence was found in Mutale municipality (82.1%) and the lowest was found in Thulamela municipality (66.7%). *Tuta absoluta* (South American tomato pinworm) and *Spodoptera frugiperda* were reported as new insect pests in Vhembe District. *Tuta absoluta* was only reported in Musina municipality. *Spodoptera frugiperda* was significantly higher in Makhado irrigated system (72%) and was significantly different from Musina municipality (8.3%) and Thulamela dryland system (19%). *Bagrada hilaris* (bagrada bug) and *Acanthoplus discoidalis* (armoured bush cricket) were observed as emerging pests in the district. Thulamela dryland system (73%) was significantly different from Thulamela irrigated system (33%) and Musina municipality (41%) in terms of *Bagrada hilaris* prevalence. Musina municipality (50%) was significantly different from the rest of the municipalities with respect to *Acanthoplus discoidalis* prevalence ($P < 0.05$). The lowest prevalence of amoured cricket was found in Mutale irrigated system (9.52%).

All municipalities showed that they highly depended on chemical control for pest management. All municipalities except Makhado dryland system, mentioned that chemicals were effective for insect pest management. The percentage of farmers who agreed that chemicals were effective was significantly different from farmers who did not agree that chemicals were effective ($P < 0.05$).

The overall study showed that climatic factors increased the prevalence of insect pests in Limpopo Province. High temperatures could have influenced the population and distribution of insect pests. New insect pests observed seemed to have quickly adapted to climatic factors in Limpopo Province and therefore, resulted to severe damage on host crops. The study also emphasized that chemical control was effective for insect pest management. However, farmers were over applying pesticides to kill insect pests. This resulted in high levels of pesticide resistance. Frequent application of pesticides can be harmful to the environment and to human health, and can also increase the level of pesticide residues on vegetables. More studies need to be conducted on the biology of new and emerging insect pests in Limpopo Province. Awareness on new and emerging insect pests must be raised to assist farmers in preparedness on how to manage insect pests. Farmers need to be trained more on chemical control measures and other control measures such as integrated pest management and biological control for pest management. The government should also train extension officers on climate change and insect pests, climate smart agriculture and effects of pesticides in order to deliver relevant advisory services to farmers.

Keywords: chemical control, warmer winters, late rainfall, research services, advisory services

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: IMPACTS OF CLIMATE CHANGE AND VARIABILITY ON EMERGING AND NEW PESTS

1.1. Introduction

Agriculture is well known to play a significant role in the world for providing food security, job creation and income for the country (Oliveira et al., 2014). Agriculture is mostly affected by threats such as climate change, pests and diseases. Weeds account for 34 % loss in crop production while insects and disease account for 18 % and 16% respectively (Oerke, 2006). According to Oliveira et al (2014), insect pest damage can result into yield loss of ± 25 million tons of food and this may result in challenges in meeting food demand. Due to damages resulting from these pests, crop loss has been increasing for the last 40 years (Oerke, 2006).

Climate change is one of the greatest threats to the world's development. Climate change is defined as change in the state of climate and can be identified by changes in the mean and variability of its properties that persists for an extended period, typically decades or longer (IPCC, 2007). Climate change may result from natural processes, anthropogenic behaviour, or by changes in the compostion of the atmosphere or land use (IPCC, 2007). Human activities such as burning of fuels contribute to greenhouse gas emissions resulting in global warming (Michalak, 2016). It is said that due to these greenhouse gas emissions and the impact they have on crops; agricultural production is most likely to be reduced. Africa as a continent and other developing countries are most likely to be vulnerable to climate change and variability (Slingo et al., 2005). In South Africa, the most vulnerable provinces are Limpopo, KwaZulu-Natal and Eastern Cape (Gbetibouo et al., 2010). These provinces are more vulnerable to climate change because there are large numbers of smallholder farmers who depend on rain fed crop production. In addition to these, most of the land used for farming is degraded (Gbetibouo et al., 2010). Climate change is most likely to result in the overburdening of the less privileged farmers who are already highly vulnerable to climatic changes (Gbetibouo and Ringle, 2009).

Agriculture is a climate sensitive sector and it is the main livelihood strategy for smallholder farmers in Africa. Climate change and extreme weather events are already posing a huge threat to food security (Gregory et al., 2009). Smallholder farmers have already started experiencing the challenges brought by climate change (Harvey et al., 2014). However, there are signs that farmers are adapting to climate change through applying their experiences and putting some of the farming methods into practice (Gornall, et al., 2010), such as planting drought tolerance crops (Elum et al., 2016). In South Africa, the most adaptation measures used by farmers include staggering planting dates and irrigation of crops (Bryan et al., 2009). Although farmers are trying to adapt to climate change, they are still vulnerable to climatic risks that may impact negatively on their crop production even in the future (Thamo et al., 2017). Most farmers are not applying these adaptation measures. Farmers have other barriers that make them fail to adapt to climate change. Most smallholder farmers do not have insurance to assist themselves in climate adaptation strategies and they also lack exposure to risk awareness (Elum et al., 2016). In South Africa the problem is lack of capital, access to information and land availability. This lack of information is more influenced by the fact that many farmers in South Africa lack access to extension services. This leaves them with no or little experience that will help them to know when to act and how to adapt to climatic risks (Bryan et al., 2009). Therefore, it is more important that extension services and policy makers should make information more accessible and useful to farmers to reduce their vulnerability to climate change risks.

The global mean temperatures have increased by 0.74 ^{o}C in the last century and are still predicted to rise by 3.4 ^{o}C in the 21st century and this will impact heavily on agriculture (Barzman et al., 2015). It has been documented that South Africa is also experiencing significant changes in temperature and rainfall patterns. Temperatures have shown to be increasing over years in South Africa (Elum et al., 2016). Most insect pests affecting crop production are poikilothermic which can easily adapt to temperature changes. Global warming can result into emergence of new insect pest species, increased geographical range of insect pest, and increase of insect invasion through migration to other areas and also increased use of pesticides that may lead to insect pests developing resistance (Reddy, 2013). Global warming can also influence the behavior of pests, population, the distribution dynamics and the relationship between the host and insect pests (Durak et al., 2016). Atmospheric carbon dioxide is also projected to increase by the end of 21st century and this increase will also be accompanied by a change in insect pests and their distribution (Gregory et al., 2009). As a result of these factors, South Africa is most likely to undergo great losses in crop production due to pests if no action is taken (Ziska and McConnell, 2016). The relationship between the host and insect pest can be positively influenced by an increase in carbon dioxide. If the host and insect pests are having a positive relationship, insect pests tend to increase their feeding behaviour and also increase their reproduction rate. This can influence the abundance of insect pests and the damage they can cause on crops (Raza et al., 2015). Very little information has been documented about the impact of increasing temperatures and carbon dioxide on insect pests in most African countries.

The emerging pests that are most common in the African countries are aphids, whiteflies, grasshoppers and also caterpillars (Nambangia et al., 2016). Some of these emerging pests spread viruses and can result in economic yield loss of major crops when influenced by global warming. Whiteflies have been found to be spreading *Begomoviruses* which are said to be an emerging threat in the West and Central Africa and South Africa (Leke et al., 2015; Moodley et al., 2016). Aphids are known to spread disease such as the *Barley yellow dwarf virus* which is one of the most important disease in crop production (Trebicki et al., 2015; Vassiliadis et al., 2016). Insect pests can adjust to high temperatures and high carbon dioxide levels. With these changes projected to occur, South Africa is most likely to experience the same problem of crop damage that other countries are facing due to emerging pests and diseases. Farmers may experience high crop losses due to high infestations of insect pests in their farms and this will drain their financial resources in order to control these pests.

1.2. Justification of the study

South Africa has several provinces that experience high temperatures such as Limpopo, KwaZulu-Natal and Northwest. These provinces are expected to experience a high infestation of emerging pests and diseases that can create huge losses in crop production (Moodley et al., 2014). Most studies conducted have been focusing on climate change and crop yields. More work has been done concerning climate change and pests in other counties such as Europe and United Kingdom (Bale, 2002; Kiritani, 2006; Bell et al., 2015). In South Africa, only few studies have recently been published on emerging pests and diseases and how smallholder farmers adapt to climate change and how they can sustain food security (Moodley et al., 2016). Few studies have concentrated on how smallholder farmers perceive climate change and how it influences the emergence and spreading of insect pest and diseases (Kisten et al., 2016). With gradual increase in temperature and carbon dioxide, South Africa will experience a high rate of reproduction of insect pest and high occurrence of emerging pests.

This will raise a major concern on the management of insect pests. There is a need to address the knowledge gap on climate change and emerging insect pests in South Africa as well as to device effective control measures that smallholder farmers can apply to sustain food security. The responses of insect populations that is enhanced by climatic changes and variability will result in evaluation of pest management strategies that should be implemented in crop production by farmers and researchers.

1.3. Major objective

The major objective of this study was to investigate new and emerging problematic insect pests under climate change in Limpopo Province, South Africa.

1.3.1. Specific objectives:

- To identify new and emerging insect pest outbreaks under climate change in Limpopo Province of South Africa
- To evaluate the farmer's perception and knowledge on climate change and insect pests
- To determine control measures used by farmers on new and emerging pests
- To determine the role of institutions in pest management in vegetable production amongst smallholder farmers in Limpopo Province

1.4. Hypotheses of the study

- Climate change and variability such as increasing winter and summer temperatures, extreme events, droughts and flood are hypothesized to increase pest burden in Limpopo Province
- Trade and globalization and poor phytosanitary practices are potentially responsible for emergence of new none endemic pest in Limpopo Province
- Farmer pest control methods which are predominantly chemical control, using synthetic insecticides are potentially responsible for insect pests developing resistance to chemicals
- Government support services from extension, research and other advisory institutions can enhance capacity of farmers to manage pests sustainably

1.5. Materials and methods

This study was conducted in Limpopo Province of South Africa in four municipalities of Vhembe District. The municipalities were Thulamela, Makhado, Mutale and Musina (Figure 1.1). This province was selected because it is known to be extremely vulnerable to climate change (Gbetibouo et al., 2010). This province is prone to higher temperatures which might result in the emergence of new pests and diseases. This study concentrated on smallholder farmers in irrigated and dryland systems. Hundred and sixty-three farmers were randomly selected within each municipality for data collection. In this study quantitative and qualitative participatory methods for data collection were used. These included survey questionnaires, key informants and focus group discussions. Focus groups discussions were composed of seven men alone, seven women alone and a combined group of seven men and seven women farmers. Extension officers and old age farmers in each municipality served as key informants. The data was analyzed using statistical package for social sciences (SPSS) to compare farmer's responses across municipalities.

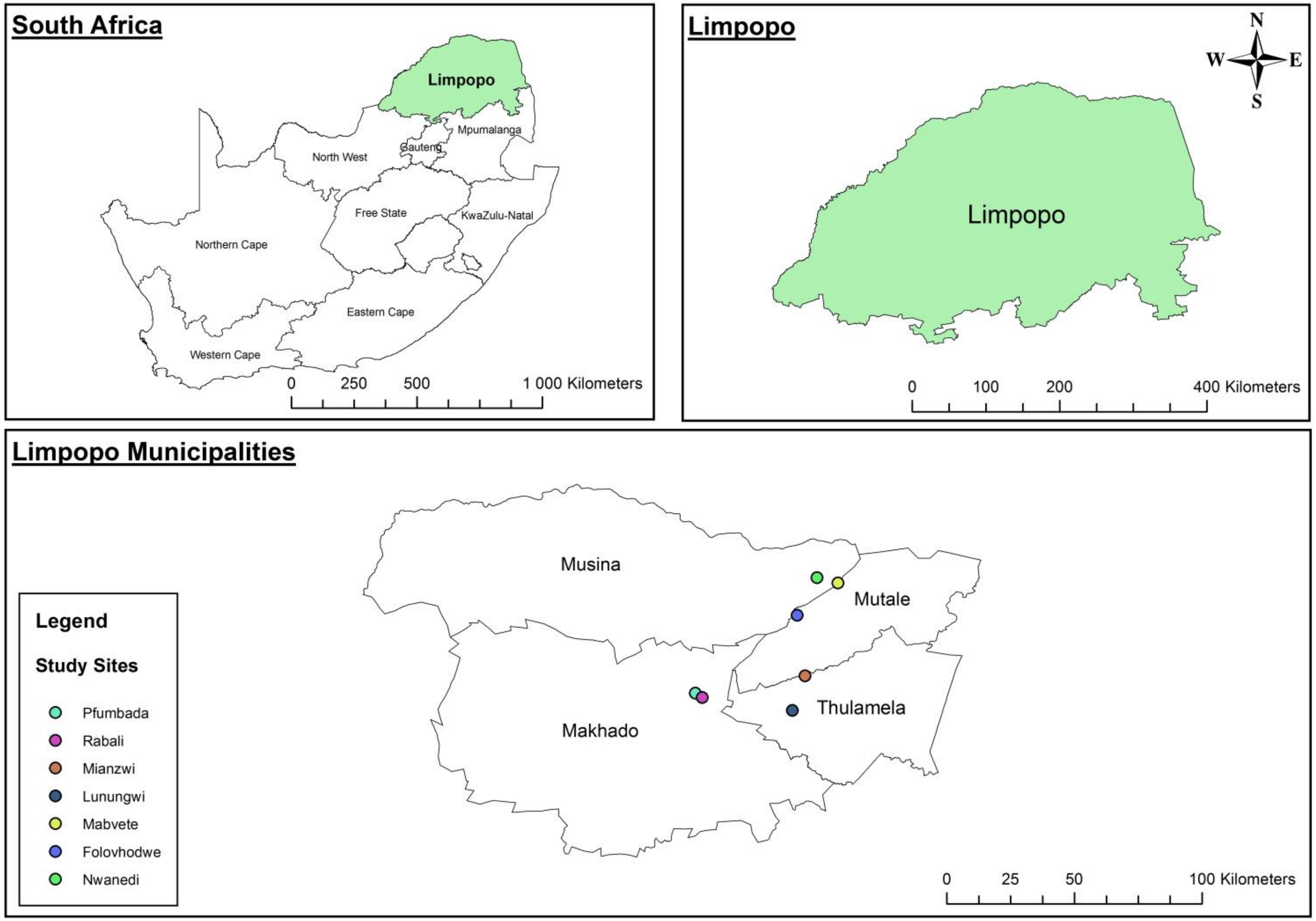

Figure 1.1: Research study area

1.6. Thesis outline

The thesis is comprised of seven chapters. Chapter one is introducing the whole study and its importance. Chapter two is the literature reviewed on the subject of this study. Chapter three is based on farmer's perceptions on climate change and insect pests. This chapter evaluated farmer's knowledge on problematic insect pests of vegetables and field crops. Farmers were evaluated on the knowledge of problematic insect pests' behavior, damage symptoms on crops, and their knowledge on insect pest problems from the past decade to present. Chapter four consist of new and emerging pests of vegetables and field crops in Limpopo Province. New and emerging insect pests were identified by farmers. This chapter also evaluated the prevalence of insect pests in different seasons. Chapter five is based on evaluation of pest control measures on vegetable crops. In this chapter, farmers were evaluated on control measures they used to manage insect pest and their knowledge on other different control measures. The application frequency of chemicals was also evaluated. Chapter six consist of the role of institutions in supporting pest management in smallholder farmers. This chapter evaluated the role of different institutions in farmer's pest management constraints in Vhembe District. Chapter seven highlighted the major conclusion and recommendations from this study.

References

Bale, J.S. (2002). Insects and low temperatures: from molecular biology to distributions and abundance. *Philosophical Transactions: Biological Sciences 357,* 849-862

Bell, J.R., Alderson, L., Izera, D., Kruger, T., Parker, S., Pickup, J., Shortall, C.R., Taylor, M.S., Verrier, P., & Harrington, R. (2015). Long-term phenological trends, species accumulation rates, aphid traits and climate: five decades of change in mitigating aphids. *Journal of Animal Ecology, 84,* 21-34

Barzman, M., Lamichhane, J.R., Booij, K., Boonekamp, P., Desneux, N., Huber, L., Kudsk, P., langerell, S.R.H., Ratnadass, A., Ricci, P., Sarah, J., & Messean, A. (2015). Research and development priorities in the face of climate change and rapidly evolving pests. *Sustainable Agriculture Reviews, 17,* 1-7

Bryan, E., Deress, T.T., Gbetibouo, G.A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environmental Science & Policy, 12,* 413-426

Durak, R., Wegrzyn, E., & Leniowski, K. (2016). Do all aphids benefit from climate warming? An effect of temperature increase on a native species of temperate climate zone Cinara juniper. *Ethology Ecology & Evolution*, *28,* 188-201

Elum, Z.A., Modise, D.M., & Marr, A. (2016). Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa. Climate Risk management. *Climate Risk Management, 16,* 246-257

Gornall, J., Betts, R., Burke, E., Clarck, R., Camp, J., Willet, K., & Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transaction of the Royal Society B, 365,* 1973-2989

Gbetibouo, G.A., & Ringle, C. (2009). Mapping South African sector vulnerability to climate change and variability. IFPRI Discussion Paper 885. Washington, D.C. (USA): IFPRI.

Gbetibouo, G.A., Ringler, C., & Hassen, R. (2010). Vulnerability of the South African farming sector to climate change and vulnerability: An indicator approach. *Natural Resource Forum, 34,* 175-187

Gregory, P.J., Johnson, S.N., Newton, A.C., & Ingram, J.S.I. (2009). Integrating pests and pathogens into the climate change/food security debate. *Journal of Experimental Biology, 60,* 2827-2838

Harvey, C.A., Rakotobe, Z.l., Rao, N.S., Dave, R., Razafimahatratra, H., Rabarijohn, R.H., Rajaofara, H., & MacKinnon, J.L. (2014). Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of Royal Society B, 309,* 20130089

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kiritani, K. (2006). Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. *Population Ecology, 48,* 5-12

Kisten, L., Moodley, V., Gubba, A., & Mafongoya, P. (2016). First detection of Tomato Spotted Wilt Virus (TSWV) on *Amaranthus thunbergii* in South Africa. *Plant Disease, 100,* 2176

Leke, W.N., Mignouna, D.B., Brown, J., & Kvarnheden, A. (2015). Begomovirus disease complex: emerging threat to vegetable production systems of west and Central Africa. *Agriculture and Food Security, 4,* 1

Michalak, D. (2016). A comparative analyses of initiatives and adaptation measures to climate change undertaken in Poland and Western Europe. *Comparative Economic Research, 9,* 107-122

Moodley, V., Ibaba, J.D., Naidoo, R., & Gubba, A. (2014). Full-genome analyses of a Potato Virus Y (PVY) isolate infecting pepper (*Capsicum annuum* L.) in the Republic of South Africa. *Virus Genes, 49*, 466-476

Moodley, V., Gubba, A., & Mafongoya, P. (2016). First report of Tomato torrado virus on Tomato (*Solanum lycopersicum*) in South Africa. *Plant Disease, 100*:231

Nambangia, J.O., Afari-Sefa, V., Bidogeza, J., Tata, P.I., & Ngome, F.A. (2016). An evaluation of smallholder farmers' knowledge, perceptions, choices and gender perspectives in vegetable pests and disease control practices in the humid tropics of Cameroon. *International Journal of Pest Management, 62,* 165-174

Okolle, N.J., Afari-Sefa, V., Bidogeza, J.,Tata, P.I., & Ngome, F.A. (2016). An evaluation of smallholder farmers' knowledge, perceptions, choices and gender perspectives in vegetable pests and diseases control practices in the humid tropics of Cameroon. *International Journal of Pest Management, 62,* 165-174

Oerke, E.C. (2006). Crop losses to pests. Journal of Agricultural Science. 144:31-43

Oliveira, C.M., Auad, A.M., Mendes, S.M., Mendes, S.M., & Frizzas, M.R. (2014). Crop losses and the economic impact of insect pests on Brazilian agriculture. *Crop Protection, 56,* 50-54

Reddy, P.P. 2013. Impact of climate change on insect pests, pathogens and nematodes. Pest *Management in Horticultural Ecosystems, 19,* 225-233

Slingo, J.M., Challinor, A.J., Hoskins, B.J., & Wheeler, T.R. (2005). Introduction: food crops in a changing climate. *Philosophical Transactions of the Royal Society B, 360,* 1783-1989

Thamo, T., Addai, D., Pannell, D.J., Roberston, N.J., Thomas, D.T., & Young, J.M. (2017). Climate change impacts and farm level adaptation: economic analysis of a mixed cropping livestock system. *Agricultural Systems, 150,* 99-108

Trebicki, P., Nacarrow, N., Cole, E., Bosque-Perez, N.A., Constable, F.E., Freeman, A.J., Rodoni, B., Yen, A.L., Luck, J.E & Fitzgerald, G.J. (2015). Virus disease in wheat predicted to increase with a changing climate. *Global Change Biology, 21,* 351-3519

Vassilaidis, S., Plummer, K.M., Powell, K.S., Trebicki, P., Luck, J.E., & Rochfort, S.J. (2016). The effect of elevated Co_2 and virus infection on the primary metabolism of wheat. *Functional Plant Biology, 43,* 892-902

Ziska, L.H., & McConnell, L.L. (2016). Climate change, carbon dioxide and pest biology: monitor, mitigate, and manage. *Journal of Agriculture and Food Chemistry, 64*, 6-12

CHAPTER 2: LITERATURE REVIEW[1]

Abstract

Vegetable production worldwide is constrained by pests and diseases whose effects are exacerbated by climate change and variability. Greenhouse gas emissions are also increasing due to poor agricultural practices and other human activities. This will continue to have a negative impact on the prevalence of insect pests and diseases. This review focuses on the climatic factors that impact on insect pests and diseases of vegetable crops. High atmospheric temperatures and elevated carbon dioxide increases pest development, survival of pests and distribution of pest to new areas. The distribution of insect pests and diseases are not due to climate changes only but are also a result of globalization and poor biosecurity measures at country borders. There is limited information on the distribution of pests and diseases due to globalization in African countries. New exotic pests will continue to be introduced to countries if biosecurity measures are not improved. Future research must focus on how to manage emerging pests and diseases influenced by high temperatures and carbon dioxide and other climatic conditions, which influence pest severity under smallholder farmers in the southern African regions.

Key words: Biosecurity, emerging pests, insect pest management, smallholder farmers

2.1. Introduction

More undernourished people are found in African regions and this has remained a great challenge in the Sub-Saharan Africa (FAO, 2015). South Asia and Sub-Saharan Africa constitutes at least one billion people who suffer from malnutrition, lacking carbohydrates, vitamins, and other micronutrients (Keatinge et al., 2011). Smallholder farmers do not only grow vegetables for income purposes but also for improvement of human nutrition at household level. Vegetables are rich in essential micronutrients such as vitamin A, C, E, zinc, copper, iron and antioxidants (Afari-Sefa et al., 2016). FAO (2004) recommended that a human being needs to consume 200 g of vegetables per day. However, vegetable consumption is still below 200 g per day especially for the poor and this result in the rising rates of malnutrition (Keatinge et al., 2011).

---

[1] This chapter is based on a paper published in the Journal of Agricultural Science volume 9: pages 11-25 in 2017.

The major common constraints to vegetable production in smallholder farmers are pests and diseases and this limits farmers in obtaining better crop yield and ensuring food security. Some smallholder farmers have adopted the use of chemicals to manage insect pests and diseases in vegetable production. However, there is a challenge of insect resistance that is building up and this is becoming a constraint to insect pest management and obtaining good crop yields (Jallow et al., 2017). The overuse of pesticides is also leading to health problems and affecting the environment negatively when not handled properly. Jallow et al. (2017) indicated that 65% of farmers agreed that the use of chemicals for insect management is hazardous to the environment and 70.5% confirmed that pesticides could be dangerous to human health. This will remain a huge problem to farmers who depend on chemicals to manage insect pests, especially when climate change is having an impact on the biology and distribution of insect pests.

2.2. Greenhouse gas emissions

The increase of greenhouse gas emissions resulting from human activities and other natural factors has become a worldwide threat affecting the environment through climate change. These activities include the use of fuels and deforestation and are contributing to the elevation of carbon dioxide and increase of temperatures (Olabemiwo et al., 2017). Carbon dioxide contributes 58.8% greenhouse gasses (Olabemiwo et al., 2017). Agricultural practices can also contribute to the emission of greenhouse gases when carbon dioxide is being released. Carbon dioxide can be released through burning of plant materials and through decomposition of soil organic matter (Kang and Banga, 2013). These emissions of greenhouse gasses are expected to increase because human population is increasing and it depends on agriculture for food (Kang and Banga, 2013). The use of fertiliser in crops also contributes to greenhouse gas emissions. Nitrous oxide can be emitted when using nitrogen fertilizers. Farmers can find other alternatives of fertilizing their crops with less emission of greenhouse gasses.

2.3. Climate variability

Extreme weather events such as heavy rainfalls leading to floods, severe droughts and extreme heat waves have been increasing since the past decades and are still expected to increase in the next few decades to come (Mirza, 2011). These processes will continue to have implications on agricultural productivity on a global scale (Gornall et al., 2010). Climate change is most likely to alter insect pests and the relationship between the host and insect can be affected (Bale et al., 2002) thus resulting in negative impact on crop productivity. Some crops, which are known to be resistant to insect pest, can become susceptible and react positively to pest damage under the influence of climate change and global warming (Reddy, 2013).

Climate change and global warming can result in observable changes to insect pest life such as migration of insect pest and invasion to other areas, increase in geographical range of insects, and influencing the population of insect pests by increasing their rate of development and cycles within a short period of time (Reddy, 2013). All these changes resulting from climate change can contribute to difficulty to predict the effect of pest management and this can result in low crop yields. In addition, a one-year change of climate can influence pest outbreaks and if the pests are aggressive enough, there can be a regime shift of insect pests (Kiritani, 2013). Insect pests that are most affected by climate change and global warming are those that are ectothermic because they can quickly acclimatize to different environmental conditions. This gives them an advantage to multiply aggressively, increasing their threat to crop production (Ferrer et al., 2014). Examples of insect pests that easily adapt to high temperatures include, aphids, whitefly and stem borers (Sharma and Prabhaka, 2014).

Increased temperatures and elevated atmospheric carbon dioxide are the most conspicuous factors of climate change that have become a threat to crop production (Mendelsohn, 2008). These two factors have been increasing and are still predicted to increase by the end of twenty-first century (Trebick et al., 2015). The two factors have resulted in shifts of pests from lower latitudes to higher latitudes (Barzman et al., 2015) and also altered insect pest pressures negatively through emerging pests and positively through migration, thus creating consequences to the environment and to crop productivity (Ziska and McConnell, 2016).

2.4. Impact of temperature on insects and disease

Global warming exerts extensive effects on insect life and the terrestrial ecosystem and it is still predicted to cause major changes in the near future. Temperature increase has been predicted to elevate by 3.4 ^{o}C by the end of twenty-first century (Barzman et al., 2015). With all these predictions, vegetable production in dryland areas will continue to be vulnerable to these temperature effects (Macfadyen et al., 2016). Policy makers can be able to make use of these predictions to make suitable policies for farmers on management strategies of mitigation and adaptation to pests impacting crop production (Sharma and Prabhakar, 2014). Global warming can affect insect population in a number of ways such as: changes in population growth rate, the increase in number of insect generations, the extension of geographical range, the introduction of species to alternative host plants, the increase of invasion risk by migrating insects and also overwintering of insects (Bale et al., 2002; Maran and Pelini, 2016).

High temperatures can alter the growth and development of insects affecting the fecundity and mortality of insects (Khaliq et al., 2014). The increase in insect population numbers occurs when the growth and developmental rate has been speed up. For example, short living insects that have adapted to high temperatures can be able to increase the number of generations in a year when influenced by warmer conditions (Van Dyck et al., 2014). Meisner et al. (2014) showed that higher temperatures increased aphid (*Aphidius ervi*) growth and developmental rate and increased the span of adult life under 20 ^{o}C and 27 ^{o}C. This means that the higher the developmental rate, the more the insect cycles and the higher the population size. This can result in more severe damage to crops if farmers are failing to control insect pests.

Different stages in the life cycle of an insect can respond differently to high temperatures (Zhang et al., 2015). Some insects can be highly favoured by high temperatures, influencing their population positively, whereas some insects can result in high mortality rates under high temperatures. Diamondback moth (*Putella xylostella*) has been monitored under high temperatures and it was reported that its growth and development was affected by temperature. Egg production and the adult stage of this insect were decreased at higher temperatures. However, the larval stage was found to be highly tolerant to high temperatures (Zhang et al., 2015). This means that there could be implications when managing this insect pest under high temperatures in the near future. *Aphidius ervi* found in peas was found to be tolerant when monitored in high temperatures. High temperatures influenced the increase in the developmental rates of this aphid and the adult stage was found to be more tolerant to high temperatures thus resulting in increased rates of pea damage (Meisner et al., 2014). Most insects have the potential for long distance mobility and flight. High temperatures can increase the mobility of some insects as well as their distribution. Most insects usually move to the northern regions were they are able to disappear from unsuitable climatic conditions (Ziska and McConnel, 2016). Most of these insects that have high rates of migration are ectotherms and this type of insects is expected to continue shifting to higher latitudes and altitudes in the next decades (Vanhanen et al., 2007). It has been predicted that insects will shift by 6.1 km to the upward poles per decade due to increased temperatures (Parmesan and Yohe, 2003). In the UK, the lepidopteran moths and butterflies have been reported each year to have increased in migration rate and this has been linked to increased temperatures in the southwest Europe (Sparks et al., 2007). *Grapholita molesta* (Busck), a lepidopteran moth has the potential to adapt to high temperature environment and has been found to have good flying abilities under high temperature (Ferrer et al., 2014). In Africa, smallholder farmers are most likely to be vulnerable to this factor because severe high temperatures are predicted to be experienced in African areas (Biber-Freudenberger et al., 2016). *Tuta absoluta*, *Ceratitis cosyra* and *Bactrocera invadens* are the most common insect pests found in Africa and they have been recorded to increase their suitability to different types of environment across the African continent (Biber-Freudenberger et al., 2016). The advantage to habitat suitability by insect pest can influence the increase of the ability to spread and acclimatize to different environments while at the same time causing damage to crops.

High winter temperatures can affect and influence the presence and outbreaks of insect pest (Reddy et al., 2015). Warmer winters can result to reduction in mortality rates of insect pests and this often leads to high infestations on crops thus increasing the damage and yield loss (Harrington et al., 2001). Warmer winters can also increase the distribution of insect pests because of reduced mortality rates (Battisti et al., 2005). The African bollworm (*Herlicoverpa amigera*) is regarded as one of the major insect pest in agricultural production. This insect has the ability to overwinter due to increased temperatures in winter season (Reddy et al., 2015). The southern green Stinkbug (*Nezara viridula*): heteroptra: pentatomidae) showed a high survival rate in winter season due to increased warmer conditions (Musolin et al., 2009). It can be expected that due to high temperatures, warmer seasons can be long and therefore resulting in warm winter conditions that can lead to high presence of insect pest.

Temperature, light and water are the main factors that control and influence the development of plant diseases, their survival, the rate of multiplication and the rate at which inoculums disperse and penetrate on plants, spreading the diseases on plants (Ahanger et al., 2013).

Increased temperatures influence the growth and development of most plant pathogens. Pathogens that depend on temperature for development can be active due to high temperature, and if utilizing the warmer conditions, they can develop and start spreading on crops if left uncontrolled (Ahanger et al., 2013). Most plant pathogens that have a short life cycle may reproduce rapidly and have a high distribution rate when exposed to higher temperatures (Coakley et al., 1999). When temperatures are high, pathogens can migrate to new areas where there are potential susceptible hosts that can influence the development of diseases (Etterson and Shaw, 2001). Plants that grow in the tropics are the ones that are usually affected by diseases that are influenced by high temperatures. This is because these plants have a narrow temperature growth range and they are quick to respond positively to temperature changes (Ghini et al., 2011). Late blight diseases have been recorded in the earlier ages to be aggressive at 10-25 ^{o}C temperatures. However, recently these diseases have now adapted to higher temperatures of up to 27 ^{o}C (Luck et al., 2011). Due to predictions of increasing temperatures in this century, pathogens are most likely to be found in large numbers and resulting in difficulties in controlling them.

High temperatures can influence the development and spread of stem rust caused by *Puccinia graminis f*. sp *tritici* (Gautam et al., 2013). Stem rust has been reported to be more aggressive when temperatures are high and it has shown to be quick in adapting to high temperature changes (Mboup et al., 2012). Bacteria such as *Rasoltonia solanacearum* was also reported that it grows and develops rapidly due to high temperatures. High temperatures with low rainfall can also influence the spread of viruses such as *Maize dwarf mosaic virus* and Beet yellow virus (Clover at al., 1999; Olson et al., 1990). The severity of these diseases will affect smallholder farmers because of high vulnerability to climatic changes and lack of knowledge to manage diseases.

2.5. Extreme weather events

Climate change can result in extreme weather events that can have an impact in agricultural production and insect pests and diseases (Adamo et al., 2012). These extreme events include long periods of drought spells, long spells of heavy rainfall and extreme high temperatures (Rosenzweig et al., 2001). The long spells of high temperatures and drought are linked to El Nino scenarios (Rosenzweig et al., 2001). Long dry spells and drought can enhance insect population growth rates and reproduction rates (Adamo et al., 2012). Pests found in the temperate regions are predicted to be more affected by extreme weather events. They are predicted to increase in population during long dry spells (Adamo et al., 2012). A study was done in South Africa on some of the problematic fruit flies (*Ceratitis capitata*) commonly known as the medfly and *C. rosa* commonly known as the Natal fruit fly. These fruit flies showed an increase in their abundance due to extreme high temperatures. However, their fecundity rates showed to decrease in low temperatures (Nyamukondiwa et al., 2013). The lower temperatures in the Western Cape province of South Africa can have an influence in reducing the effectiveness of these flies, therefore high rates of mortality and less damage to the fruits (Nyamukondiwa et al., 2013).

Heavy rainfall affects insect biology and survival negatively. Most insects are vulnerable to heavy rainfall, thus affecting their growth development and population (Pellegrino et al., 2013). Heavy rainfall can result to increased mortality rates of insects (Pellegrino et al., 2013). A study was done and showed that heavy rainfalls can result to high rates of locust mortality. Heavy rainfalls affected the locust eggs and the nymph survival was reduced severely (Woodman, 2015). Extreme weather events can result to insect pest outbreaks (Ju et al., 2013). These outbreaks can wipe out crop species due to severe damage and spread of diseases. They can also influence invasion of alien pest species that may have an impact in crop yield (Kannan and James, 2009). However, invasion of new species due to extreme events will also depend on whether the insect is adapting well to the new environment and climatic conditions (Sharma and Prabhaka, 2014). Frequent heavy rainfall can influence the spread of pathogens and fungal diseases. Many plant pathogens are known to respond positively when there is rainfall (Thompson et al., 2013). Plant pathogens such as *Phytophthora cinnamomi* and *Botryosphaeria doithidea* are amongst the many pathogens that are known to respond positively when there is rainfall (Thompson et al., 2013).

2.6. Impact of elevated carbon dioxide on insects and diseases

Presently, the level of atmospheric carbon dioxide is 400 μmol^{-1} and it is predicted to potentially increase by the end of 21st century to 650 μmol^{-1} (Trebecki et al., 2015; Vassiliadis et al., 2016). Most studies have been done on the impact of carbon dioxide on crop plants but little is known about atmospheric carbon dioxide on plant insect pests and diseases. Carbon dioxide can affect plant growth and development by altering the physiology and morphology of the plant. Such alterations induced by carbon dioxide can affect the diet quality and feeding behaviour of insects (Ryan et al., 2014). Although these alterations affect the feeding behaviour of insects, insects are affected differently. Elevated carbon dioxide was found to have an impact in the lepidopteran *Herlicoverpa amigera*. The feeding behaviour of the larvae was affected by elevated carbon dioxide. Results showed that elevated carbon dioxide contributed to the increase of food consumption and metabolism of the larvae and this gives an indication that *Helicoverpa amigera* larvae may cause more damage under elevated carbon dioxide (Akbar et al., 2016). *Herlicoverpa amigera* is one of the major global insect pest that feed on brassicas and its damage can lead to high yield loss (Machekano et al., 2017). The ability of this insect pest to cause damage can be highly influenced by climatic change (Machekano et al., 2017). Sucking insects such as aphids can also be affected by elevated carbon dioxide (Newman, 2003). Some studies show an increase in aphid population due to elevated carbon dioxide (Newman, 2003). However, some plants can produce defensive compounds, which can affect the feeding, development and survival of sucking insect pests (War et al., 2012).

Elevated concentrations of carbon dioxide are most likely to affect the pressure of insect pest in both managed and unmanaged crops. These pressures from insect pests can either be in a form migration to new areas or they can be in a form of new introduction in areas (Ziska and McConnel, 2016), and these often underlies their distribution and abundance, hence the level of damage they cause to crops (Mazzi and Dion, 2012). Elevated concentrations of carbon dioxide also affect insect pest growth and their development and this often results in changes in the interaction between insect pests and their crop host (Akbar et al., 2016; Elad and Pertot, 2014).

Carbon dioxide also has an impact on plant diseases. Carbon dioxide influences the growth and development of the crops, crop canopy and the microclimate as well as the quantity of tissues susceptible to diseases (Pannga et al., 2013). The canopy microclimate can influence the presence, survival and dispersal of plant pathogens (Pannga et al., 2013).

Elevated carbon dioxide may result in extreme changes of reproduction, spread and severity of plant diseases and this is a threat to food security (Gautam et al., 2013). Plant diseases can result from bacteria, fungi and viruses and their interaction with plants can be highly influenced by weather patterns including elevated carbon dioxide (Nopsa et al., 2014). A range of foliar diseases can be encouraged by dense canopies due to increased carbon dioxide. Such foliar diseases that are influenced by elevated carbon dioxide include powdery mildew, rust, leaf spots and blights and these diseases are known to develop in warm weather conditions (Gautum et al., 2013). Diseases such as late blight (*Phytopthora infestans*) known to infect potatoes, blast (*Pyricularia oryzae*) and sheath blight (*Rhizoctonia solani*) known to infect rice are known to cause significant damage to these crops, hence more threat under elevated carbon dioxide (Gautam et al., 2013).

2.7. Impact of globalization on spread of insect pests and diseases

Alien species can impact crop production in countries and this can lead to economic crop yield loss (Saccaggi et al., 2016). Alien species are defined as species that have the ability to live and adapt outside their natural habitat (Sujay et al., 2010). Alien species can occur in the form of insect pests, fungal diseases, viruses and other species that are also non-agricultural (Sujay et al., 2010). Most of these alien pests have the ability to outcompete native pests because they can highly adapt to new environments. They have aggressive growth and reproduction and they can move long distances at the same time spreading and causing damage to agricultural crops (Rejmanek and Richardson, 2000). The risk of these alien pests have been increasing and has become a great threat to agricultural production, especially insect pests such as arthropods due to their small size and high ability to tolerate different climatic conditions (Saccaggi et al., 2016).

Alien pest species can be introduced to the country intentionally or unintentionally. Alien pests can be introduced by movement of people and goods from one country to the other, through imports of agricultural products such as fruits, vegetables, seeds (Hulme et al., 2008) and propagation materials (Saccaggi et al., 2016). Improvement of logistic has recently resulted in the ease of commodities to be exported to different countries globally; this has been found to influence the introduction of alien pests through contamination (Hulme, 2009). The increase of transport networks, both aquatic and terrestrial, is also playing a role in the introduction of pests to other countries (Hulme, 2009). The magnitude and the level of distribution of these alien pests on agricultural products between countries is still not well-understood (Paini et al., 2016). However, it is said that the most countries to suffer from invasions by alien species are the sub-Saharan countries and those countries that receive large volumes of agricultural imports (Paini et al., 2016).

2.8. Phytosanitary measures

Biosecurity measures are taken to reduce the introduction of alien pest species in countries (Cope et al., 2016). Biosecurity includes phytosanitary measures, which are conducted at country borders. Detection of alien species are conducted whereby travelers, machines, luggage and food are inspected for hidden pests (Liebhold et al., 2006). Other methods of detection include vacuuming travelers' goods to remove small or unseen particles such as seeds and insects, preventing their entry into foreign countries (Fortune, 2006). Small insect pests are not easy to detect at the border when biosecurity measures are taken (Saccaggi et al., 2016). This becomes a problem when small insect pests with high reproductive rates pass through the border and adapt to the foreign environment. These pests then result to high damage to crop production. Some alien pests are able to enter foreign countries due to poor biosecurity measures (Caley et al., 2015). Insect pests that belong to order Coleoptera, Hemiptera, Lepidoptera and Diptera have been entering Australia during the years of 1986-2005. These pests have been recorded all these years because the biosecurity measures has been poorly facilitated, therefore increasing high rates of invasion and damage from these pests (Caley et al., 2015). To develop effective biosecurity measures, policy makers need to understand the sources of these alien pests and diseases, their rate of distribution, how they adapt to different environmental conditions and the damage they can cause of agricultural products (Bourdot et al., 2012). As indicated previously, most alien pests are introduced as contaminants; there will be an increase of challenges to policy makers and the management of these pests. There is a need to monitor the trends in which alien species are being introduced in foreign countries and the biosecurity measures should be regulated more effectively to reduce the entry of alien pest (Hulme et al., 2008).

2.9. The role of vegetables in human nutrition

The amount and types of nutrients consumed by human beings daily can affect the human's nutritional status. The lack of good nutrition in human diet may result in serious health conditions, which can affect the lifestyle of humans in future (Keatinge et al., 2011). Malnutrition conditions are very common in young children especially those in the sub-Saharan African countries (Brown and Pollitt, 1996). Lack of nutrition in children can affect the development of brain (Brown and Pollitt, 1996). However, this damage can be reversed if proper nutrients are consumed (Brown & Pollitt, 1996). A diet with high fat and sugar result in poor development and reduction of IQ in children (Northstone et al., 2011). High consumption of foods with protein, vitamins can result in better chances of increasing the children’s IQ (Northstone et al., 2011). Nutrition is also very important for pregnant women and for women who are in the reproductive phase. Foods that contain vitamins, minerals and folate are highly essential for preventing foetal damage in pregnant women (FAO/WHO, 2004). There is nutrition transition in the West African countries such as Ghana and Senegal (Bosu, 2015). There is high consumption of sugar and fatty foods leading to increasing rates of obesity by 115% since 2004 in the West African countries with less consumption of vegetables and fruits (Bosu, 2015). Studies have shown that there is increased rate of hypertension in Burkina Faso and Cape Verde due to lack of good nutrition consumption (Bosu, 2015). Lack of vitamin has been reported in 250,000 to 500,000 African children, resulting to blindness every year and half of the kids dying within 12 months of their blindness (WHO, 2013). Iron is another essential nutrient that has been reported to be deficient in the sub-Saharan countries, resulting to health consequences (WHO, 2002). There are still 2 billion people who are undernourished in African countries and this has increased malnutrition problems because food demand is higher than the food supplied (FAO, 2013). The nutrition transition in African countries does not only affect human beings in higher socioeconomic strata, but it also affects the poor and the uneducated who are already affected by poor sanitation and other diseases (Bosu, 2015).

Vegetable consumption is the first important step to overcome human malnutrition, especially to those who are more vulnerable to lack of nutrients (Yang and Keding, 2009). Vegetables are very important for reducing malnutrition problems in human beings (Ojiewo et al., 2015). Most vegetables, which contain essential nutrients, include cabbages, tomatoes, black nightshade, cowpea and soybeans. These vegetables contain nutrients such as vitamin A, vitamin E, protein, iron, folate, zinc and calcium, which are very essential for human diet (FAO/WHO, 2004). Vegetables can be made available to households when grown in home gardens. There is need to increase vegetable production for human beings to obtain essential micronutrients through their diets (Ojiewo et al., 2015). The green revolution concentrated on staple crops such as maize, wheat, rice and cassava to eliminate poverty in the African regions. However, these crops do not contain essential micronutrients (Ojiewo et al., 2015). Tenkouano (2011) suggested that these crops rather constitute to “grain revolution” than “green revolution” due to lack of micronutrients. Vegetables and legumes contains essential micronutrients and needs to be part of a well-balanced diet and has to be included as part of the green revolution (Tenkouano, 2011).

2.10. Traditional vegetables

Traditional vegetables can also be consumed to combat malnutrition problems. These types of vegetables are not usually grown and supplied on a large scale (Mampholo et al., 2016). However, they can be grown and sold locally with less management and can tolerate adverse weather conditions. Most of these vegetables are redroot pigweed (*Amaranthus retroflexus*), mustard spinach and black nightshade *(Solanum nigrum)* and are most consumed in South Africa (Mampholo et al., 2016). Traditional vegetables are rich in calcium, zinc, vitamin A, B, E, and other antioxidant compounds (Yang and Keding 2009). Absence of these nutrients in the human diet can result to what is called "hidden hunger" and other chronic diseases (Yang and Keding, 2009). Black nightshade contains compounds such as flavonoids, ascorbic acid, protein, vitamins and other minerals such as calcium, potassium and phosphorus (Van Averbeke et al., 2007). Consumption of these vegetables can help to alleviate poverty and food insecurity in rural households (Van Averrbeke et al., 2007). *Solanum nigrum* also contains high levels of zinc and magnesium (Uusiku et al., 2010). Traditional vegetables are very common in the Limpopo Province and continuous provision of these vegetables can help reduce malnutrition in households, at the same time reducing food insecurity and making income when sold to markets. However, the constraints in growing these vegetables include lack of quality seeds, varieties, shortage of water, pests and disease infestation and lack of information on markets (TsChirley et al., 2004).

2.11. Major insect pests of vegetables grown in South Africa

Most of these insect pests that causes damage to vegetables include bagrada bug (*Bagrada hilaris*), diamondback moth (*Putella xylostella*), and aphids (*Aphidoidea)*. Bagrada bug (*Bagrada hilaris*) commonly known as painted bug is a native pest in most countries including African countries. This bug is known to have originated in Asia (Halbert and Eger, 2010). Bagrada bug commonly feeds on crucifer's crops and brassica crops such as cabbages, mustard, kale and other brassica crops (Bundy et al., 2012). It has also been reported to feed on crops of other families such as *Zea mays* L., *Sorhgum bicolor* (L.) sunflower (*Helianthus annuus)* and cotton (*Gossypium hirsutum*) in the United States (Reed et al., 2011). Bagrada bug is considered as one of the major serious pests resulting to huge threats in vegetable production (Huang et al., 2014). It has been reported for the first time in Los Angeles County, Carlifornia and Anzona in 2008 (Palumbo and Natwick, 2010). This bug was found to increase its distribution to native countries including African countries. It has been reported in countries such as Zimbabwe (Grzywackz et al., 2010), Botwsana (Obopile et al., 2008), South Africa, Mozambique, Kenya and Tanzania (Infonet-Biovision, 2015). However, little is known about the host preferences of bagrada bug (Huang et al., 2014) and there is little understanding of bagrada bug distribution and damage in South Africa. Bagrada bug is a sucking insect with piercing mouthparts. Bagrada bug takes 41 days to complete its entire life cycle in conducive environments of warmer climate (Reed et al., 2013). After eclosion, female bugs become receptive to the male bug in 1-2 days and it takes 4-5 days for oviposition to occur after mating for the first time (Singh and Malik, 1993). This pest can lay 100-200 eggs underside of the leaves, stem or on loose soil. However, this pest does not lay eggs in large numbers like other insect pests; it lays eggs singly or in groups of 10 eggs (Reed et al., 2013). It can overwinter in soil cracks to escape cold weather conditions, which are not good for its survival (Reed et al., 2013). This insect is usually triggered by high temperatures for effective activity. High temperatures influences the movement and mating of bagrada bug (Huang et al., 2013). A study was done in feeding of bagrada bug and results suggested that this pest feeds effectively on Brassica crops in the afternoon and evening when temperatures are high (Huang et al., 2013). Bagrada bug can be found feeding from crop seedling to maturity stage (Divya et al., 2015; Patel et al., 2017). Studies have shown that bagrada bug can invade in newly emerging crops and causing damage to the apical meristem of the crops (Palumbo and Natwick, 2010; Huang et al., 2014). This bug uses a lacerate and flush feeding method (Hori, 2000). During feeding on crops, bagrada bug secrete saliva enzymes which results in crop damage (Reed et al., 2013). Bagrada bug also removes cell sap from the plant tissues of brassica and non-brassica crops, resulting in crop deterioration (Banuelos et al., 2013). Excessive feeding on apical meristem of vegetables can result in poor head/crown formation in cabbages and this becomes a consequence of poor marketable cabbages (Palumbo and Natwick, 2010). It may also result in death of growing plant tip and deformation of adventitious budding (Reed et al., 2013). Damage caused by bagrada bug can lead to death of plants (Huang et al., 2014). Adult or mature crops can result to malformation of leaves and circular scorching of leaves due to damage caused by bagrada bug (Reed et al., 2013). However, young susceptible crops normally show signs of wilting and death of tissues leading to death of the plant (Reed et al., 2013). Leaves of young susceptible crops can show white spots as a result of feeding by bagrada bug (Patel et al., 2017).

Diamondback moth is also one of the major global insect pests than can result to huge crop loss. It is commonly known to feed on brassica crops such as cabbages (Machekano et al., 2017). Diamondback moth is ubiquitous and it can survive throughout the whole year, feeding and resulting to crop damage (Furlong et al., 2013). This insect pest has certain factors that give it the ability to cause severe damage to crops if left uncontrolled. It has high potential of reproduction, ability to distribute and migrate to other areas, it has the ability to adapt easily to different environmental conditions, and it has high ability to reproduce throughout the whole year remaining abundant and difficult to manage (Canico et al., 2013; Furlong et al., 2013). Diamondback moth has been reported in African countries such as Kenya, South Africa, Malawi, Mozambique, Zambia, Namibia, Zimbabwe and Botswana (APR 2015). Brassica export to African countries is still in great demand although there is high incidence of Diamondback moth. South Africa is one of the countries that has great exportation of brassicas to neighbouring countries such as Mozambique, Angola, Lesotho and Swaziland (DAFF, 2015). However, this pest has been found to be a constraint in the quality of brassica crops in South Africa, and therefore this result in poor marketable products (Furlong et al., 2013). Southern African countries will continue to be vulnerable to climate change (IPCC, 2014), and this will be problematic to brassica production because diamondback moth is exacerbated by climatic changes and variability (Furlong et al., 2013). In countries such as China, diamondback moth has costed the Chinese economy about US$0.77 billion annually (Li et al., 2016).

2.12. Farmers' control methods

Most farmers use chemical method to manage diamondback moth. Research suggests that most small-scale farmers in Southern African countries rely on insecticides to manage DBM. Countries such as Mozambique has 100% reliance on chemical control (Camico et al., 2013) and Botswana has 98% reliance on chemical control for this pest (Obopile et al., 2008), while Zambia and Namibia has about 70%, reliance of chemical control (Nyirenda et al., 2011). These farmers have been found to apply insecticides at different rates and at different frequencies (Canico et al., 2013). Research has shown that most farmers in these Africa countries are applying insecticides once every three weeks to control diamondback moth. However, due to high population of this pest, farmers end up applying insecticides three times a week (Obopile et al., 2008). Such application results in insect resistance development especially if chemicals of the same mode of action are applied, therefore also causing implications in management of this pest. This type of application can also result to environmental contamination. Some farmers are applying a mixture of different chemical ingredients to control diamondback moth. However, it has been recorded that most of these farmers are doing this without any guidance from the manufacturer and therefore it becomes harmful to the environment (Ngowi et al., 2007). Diamondback moth has also been reported to be resistant to many insecticides in China (Li et al., 2016). IPM has been proved effective in reducing diamondback moth in China. China country has made more efforts to support implementation of integrated pest management and many farmers have adopted this. However, these practices need to be supported continuously to prevent more insecticide reliance by farmers (Li et al., 2016). According to the reviewed, there is little information reported on these pests in South Africa. There is a need to address the impact of climatic changes especially high temperatures on the survival and population of emerging pest in smallholder farmers. Most research has been conducted in commercial farmers and little is known about smallholder farmers and their management of these pests.

2.13. The use of companion crops for insect pest management

The use of companion crops is one of the ecological practices for smallholder farmers who do not have resources to manage insect pests that are damaging their main crops (Calumpang & Navasero, 2013). The main purpose of growing companion crops is to protect main crops from insect pests that will cause damage and therefore resulting in high yield loss. Companion crops can be grown as trap crops or intercrops and this can be referred to as the push-pull strategy. Companion crops grown as intercrops attracts insect pests, making insect pests less attractive to main crops and this is known as the "Push" (Cook et al., 2007). Companion crops grown as trap crops ensures that insect pests that may feed on main crops are reduced in numbers. This is referred to as the "Pull" (Cook et al., 2007). Companion crops grown as trap crops are usually grown around field crops (Khan et al., 2001). Napier grass (*Pennisetum purpureum* Schumach) is one of the companion crops grown around maize crop field. This grass can attract maize stem borer while reducing chances of attacking maize crops (Khan et al., 2014).

Companion crops grown as intercrops can be used as repellents for insect pests (Finch and Collier, 2011). The idea of these repellents is to release volatile chemical compounds that can deter insect pests. Insect pests are able to detect repellent companion crops from a distance away from the plant and this can cause the pest to stay away from the crop thus reducing damage to the main crops (Finch and Collier, 2011). Some of the crops that can be grown to repel insect pest are eggplant (*Solanum melongena* L.), lemon grass (*Cymbopogon citratus* Stapf) and marigold (*Tagetes erecta* L.) (Calumpang and Navasero, 2013). A study was conducted to repel corn borer using eggplant and lemon grass as repellents. Results showed that the growth rate and damage caused by corn borer was reduced. Companion crops can be artificial. These artificial crops are meant to disrupt the visual pest processes and to interfere with the host selection process by the pest (George et al., 2013). Maize can be intercropped with desmodium (*Desmodium uncinatum* Jacq DC) as a companion crop to repel stem borer moths in maize crops. It can repel stem borer moths and it has the ability to attract natural enemies of this insect pest (Khan et al., 2014).

Companion crops can be grown for more than one purpose at the same time. It can be grown to repel insect pests and to improve soil fertility. For example, *desmodium* spp crop can repel insect pests of maize at the same time it can be used to improve soil fertility through biological nitrogen fixation and organic matter improvement (Khan et al., 2014). It is always a challenge to decide on which companion crops can be effective to manage insect pest. It is of importance for farmers to know different companion crops, which are effective before planting them. Companion crops should be tolerant to drought if crop production is to be practiced in arid and semi-arid areas. These crops should also be resilient to moisture stress since erratic rainfall and unpredictable rainfall patterns are expected due to climatic changes (Khan et al., 2014). There are few studies done on companion crops for pest management, most of them have focused on field crops such as maize, sorghum and millet. Very few studies have looked on companion crops for vegetable pest management. There is very limited knowledge of herbs used as companion crops for management of insect pests on vegetable production. More studies have done trap crops to attract insect pest. Very little is known about herbs that can be used to repel insect pests of vegetables through the odour they produce. There are few studies conducted in South Africa under smallholder farmers that produce vegetables with companion crops. Therefore, there is a need for smallholder farmers who cannot afford insecticides to make use of this practice to manage pests and to reduce insecticide application on vegetable crops. This will also help to suppress the rate of chemical resistance influenced by frequent insecticide application.

2.14. Areas of new research

Most studies were conducted in temperate countries. Very few studies have been done in Africa. High temperature in South Africa must be evaluated on its effects on new and emerging pests. Modelling techniques must be used to predict the spread of new and emerging pests in South African provinces. More studies should also be done on farmer's perceptions on new and emerging pests and how it interacts with climate change and variability. Studies must be done on invasive species entering southern African countries and South Africa through globalization, trade, plants, and plant products. Regional, national and global networks should work on new and emerging pests for efficient use of resources in addressing this 21st century challenge.

2.15. Conclusion

It has been concluded that anthropogenic activities and some agricultural practices such as pesticide application and burning of fuels do influence greenhouse emissions resulting to climatic changes. Climate change and variability such as increased temperatures and levels of carbon dioxide can result in changes in the biology of an insect. This can increase mortality rates, fecundity rates, growth and development of insect and adaptation and distribution of insects to new areas. However, this depends on the type of insects and the conditions, which are conducive for development. It is concluded that insect pests such as diamondback moth, bagrada bug and aphids will continue to adapt well in warmer conditions and their distribution rate towards the North Pole will be high because they respond very well to high temperatures. It is expected that these pests will result in extreme crop damage in warmer areas if they are left uncontrolled due to increased generations and populations. It can also be expected that these pests may have high overwintering rates if temperatures continue to be high. More research has been conducted on climate change and its effect on crop yield. More research should focus on how ectothermic pests and other emerging pests should be managed when influenced by climatic changes. The distribution of insect pests and diseases does not only result from climatic changes. Globalization also plays a huge role in distributing native pests to countries. This review showed that the South African countries are expected to be more vulnerable to introduction of new pests and diseases due to poor biosecurity measures. Research should focus on long term monitoring of insect pest and diseases. New efficient strategies should therefore be introduced at the borders to limit the introduction of native pests to countries. More research has focused on the European countries. However, little is known on the introduction of new pests and diseases in the Southern African countries. This gives an indication that government should provide funding for better biosecurity measures.

References

Adamo, S. A., Baker, J. L., Lovett, M. M. E., & Wilson, G. (2012). Climate change and temperate zone insects: The tyranny of thermodynamics meets the world of limited resources. *Environmental Entomology, 41*, 1644-1652.

Afari-Sefa, V., Rajendran, S., Kessy, R. F., Karanja, D. K., Musebe, R., Samali, S., & Makaranga, M. (2016). Impact of nutritional perceptions of traditional African vegetables on farm household production decisions: A case study of smallholders in Tanzania. *Experimental Agriculture, 52*, 300-313.

Ahanger, R. A., Bhat, H. A., Bhat, T. A., Ganie, S. A., Lone, A. A., Wani, I. A., … Bhat, T. A. (2013). Impact of climate change on plant diseases. *International Journal of Modern Plant and Animal Sciences, 1*, 105-115

Akbar, S. M., Pavani, T., Nagaraja, T., & Sharma, H. C. (2016). Influence of co_2 and temperature on metabolism and development of *Herlicoverpa amigera* (Noctuidae: Lepidoptera). *Environmental Entomology, 45*, 229-236.

Arthropod Pesticide Resistance Database (IRAC). (2015). Michigan State University. Retrieved from http://www.pesticideresistance.com/display

Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., … Whittaker, J. H. (2002). Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Global Change, 8*, 1-16.

Banuelos, G. S., Dhillon, K. S., & Banga, S. S. (2013). Oilseed brassicas in biofuel Crops. In B. P Singh (Ed.), *Production Physiology and Genetics* (pp. 339-368)

Barzman, M., Lamichhane, J. R., Booij, K., Boonekamp, P., Desneux, N., Huber, L., … Messean, A. (2015). Research and priorities in the face of climate change and rapidly evolving pest. *Sustainable Agriculture Reviews, 17*, 1-27

Battisti, A., Stastny, M., Netherer, S., Robinet, C., Schopf, A., Roques, A., & Larsson, S. (2005). Expansion of geographic range in the pine processionary moth caused by increased winter temperatures. *Ecological Society of America, 15*, 2084-2096

Biber-Freudenberger, L., Ziemacki, J., Tonnang, H. Z., & Borgemeister, C. (2016). Future risks of pest species under changing climatic conditions. *PLoS ONE, 11*(4), e0153237

Bourdot, G. W., Lamoureaux, S. L., Watt, M. S., & Kriticos, D. J. (2012). The potential global distribution of the invasive weed *Nasella neesiana* under current and future climates. *Biological Invasions, 14*, 1545-1556

Brown, J. L., & Pollitt, E. (1996). Malnutrition, poverty and intellectual development. *Scientific American, 247*, 38-43

Bosu, W. K. (2015). An overview of the nutrition transition in West Africa: Implications for non-communicable diseases. *Proceedings of the Nutrition Society, 74*, 466-477

Bundy, C. S., Grasswitz, T. R., & Sutherland, C. (2012). First report of the invasive stink bug *Bagrada hilaris* (Burmeister) (Heteropter: Pentatomidae) from New Mexico, with notes on its biology. *Society of Southwestern Entomologists, 37*, 411-414

Caley, P., Ingram, R., & DeBarro, P. (2015). Entry of exotic insects into Australia: Does border interception count match incursion risk? *Biological Invasions, 17*, 1087-1094

Calumpang, S. M. F., & Navasero, M. V. (2013). Behavioural response of the Asian corn borer *Ostrinia furnacalis* Guenee (Lepidoptera: Pyralidae) and the earwig *Euborelia annulipes* Lucas (Dermaptera: Anisolabiidae) to selected crops and weeds associated with sweet corn. *Philippine Agricultural Scientist, 96*, 48-54

Canico, A., Santos, L., & Massing, R. (2013). Development and adult longevity of diamondback moth and its parasitoids *Cotesia plutellae* and *Diadegma semiclausum* in uncontrolled conditions. *African Crop Science Conference Proceedings, 11*, 257-262

Clover, G. R. G., Smith, H. G., Azam-Ali, S. N., & Jaggard, K. W. (1999). The effects of drought on sugar beet growth in isolation and in combination with beet yellow virus infection. *Journal of Agricultural Science, 133*, 251-161

Coakley, S. M., Scherm, S., & Chakraborty, S. (1999). Climate change and disease management. *Annual Review of Phytopathology, 37*, 399-426

Cook, S. M., Khan, Z. R., & Pickett, J. A. (2007). The use of push-pull strategies in integrated pest management. *Annual Review of Entomology, 52*, 375-400

Cope, R. C., Ross, J. V., Wittmann, T. A., Prowse, T. A. A., & Cassey, P. (2016). Integrative analyses of the physical transport network in Australia. *PLoS ONE, 11*, 0148831

DAFF. (2015). *A profile of the South African cabbage market value chain: Department of Agriculture, Forestry and Fisheries*. Acardia, South Africa. http://www.nda.agric.za

Elad, Y., & Pertot, I. (2014). Climate change impacts on plant pathogens and plant diseases. *Journal of Crop Improvement, 28*, 99-139

Etterson, J.R., & Shaw, R.G. (2001). Constraint to adaptive evolution in response to global warming. *Science, 294*, 151-154

FAO. (2004). *FAO STAT*. Food and Agriculture Organisation, Rome, Italy. Retrieved from http://www.fao.org

FAO. (2013). *The state of food insecurity in the world 2013*. The multiple dimensions of food security. Rome, Italy. Retrieved from http://www.fao.org

FAO. (2015). *The state of food insecurity in the world 2014*. Rome: Food and Agriculture Organisation of the United Nations. Retrieved from http://www.fao.org

FAO/WHO. (2004). *Vitamin and mineral requirements in human nutrition*. Food and Agricultural Organisation, Rome. Retrieved from http://www.fao.org

Ferrer, A., Mazzi, D., & Dorn, S. (2014). Stay cool, travel far: Cold-acclimated oriental fruit moth females have enhanced flight performance but lay fewer eggs. *Entomologia Experimentils et Applicata, 151*, 11-18

Finch, S., & Collier, R. H. (2011). The influence of host and non-host companion plants on the behaviour of pest insects in field crops. *Entomologia Experimentalis et Applicata, 142*, 87-96

Fortune, A. L. (2006). *Biosecurity at the extreme: Pathways and vectors between New Zealand and Scott Base, Antarctica* (M.Sc. thesis, University of Canterbury, Canterbury, NZ). Retrieved from http://citeseerx.ist. psu.edu

Furlong, M. J., Wright, D. J., & Dosdall, L. M. (2013). Diamondback moth ecology and management: Problems, progress and prospects. *Annals Review of Entomology, 58*, 517-554

Gautam, H. R., Bhardwaj, M. L., & Kumar, R. (2013). Climate change and its impact on plant diseases. *Current Science, 105*, 1685-1691

George, D. R., Collier, R. H., & Whitehouse, D. M. (2013). Can imitation companion planting interfere with host selection by Brassica pest insects? *Agricultural and Forest Entomology, 15*, 106-109

Ghini, R., Bettiol, W., & Hamada, E. (2011). Disease in tropical and plantation crops as affected by climate changes: Current knowledge and perspectives. *Plant Pathology, 6*, 122-132

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J, Willett, K., & Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of The Royal Society B, 365*, 2973-2989

Grzywacz, D., Rossbach, A., Rauf, A., Russell, D. A., Srinivasan, R., & Shelton, A. M. (2010). Current control methods for diamondback moth and other *Brassica* insect pests and the prospects for improved management with lepidopteran-resistant Bt vegetable brassicas in Asia and Africa. *Crop Protection, 29*, 68-79

Halbert, S. E., & Eger, J. E. (2010). *Bagrada bug (Bagrada hilaris) (Hemiptera: Pentatomidiae) an exotic pest of the cruciferae established in the Western USA*. http://www.freshfromflorida.com/pi/pest_alerts/pdf/ bagrada-bugpest-alert.pdf

Harrington, R., Fleming, R. A., & Woiwod, I. P. (2001). Climate change impacts on insect management and conservation in temperate regions: Can they be predicted? *Agricultural and Forestry Entomology, 3*, 233-240

Hori, K. (2000). Possible causes of disease symptoms resulting from the feeding of phytophagous Heteroptera. In C. W. Schaeter & A. R. Panizzi (Eds.), *Heteroptera of Economic Importance* (pp. 10-35). CRC Press

Huang, T.-I., Reed, D. A., Perring, T. M., & Palumbo, J. C. (2013). Diel activity and behaviour of *Bagrada hilaris* (Hemiptera; pentatomidae) on dessert cole crops. *Horticultural Entomology, 106*, 1726-1738

Huang, T.-I., Reed, D. A., Perring, T. M., & Palumbo, J. C. (2014). Host selection behaviour of *Bagrada hilaris* (Hemiptera: pentatomidae) on commercial cruciferous host plants. *Crop Protection, 59*, 7-13

Hulme, P. E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., … Vilà, M. (2008). Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *Journal of Applied Ecology, 45*, 403-414

Hulme, P. E. (2009). Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *Journal of Applied Ecology, 46*, 10-18

Infonet-Biovision. (2015). *Bagrada bug*. Zurich. Retrieved from http://infonet-biovision.org/node/28470

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Synthesis Report*. Fifth Assessment Report (AR5), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC: Geneva, Switzerland

Jallow, M. F. A., Awadh, D. G., Albaho, M. S., Devi, V. Y., & Thomas, B. M. (2017). Pesticide risk behaviours and factors influencing pesticide use among farmers in Kuwait. *Science of the Total environment, 574*, 490-498

Ju, H., Vander Velde, M., Lin, E., Xiong, W., & Li, Y. (2013). The impacts of climate change on agricultural production systems in China. *Climate Change, 120*, 313-324

Kang, M. S., & Banga, S. S. (2013). Global agriculture and climate change. *Journal of Crop Improvement, 27*, 667-692

Kannan, R., & James, D. A. (2009). Effects of climate change on global diversity: A review of key literature. *Tropical Ecology, 50*, 31-39

Keatinge, J. D. H., Yang, R. Y., Hughes, J., Easdown, W. J., & Holmer, R. (2011). The importance of vegetables in ensuring both food and nutritional security in attainment of the millennium development goals. *Food Security, 3*, 491-501

Khaliq, A., Javed, M., Sohali, M., & Sagheer, M. (2014). Environmental effects of insects and their population dynamics. *Journal of Entomology and Zoology, 2*, 1-17

Khan, Z. R., Pickett, J. A., Wadhams, L., & Muyekho, F. (2001). Habitat management strategies for the control of cereal stemborers and striga in maize in Kenya. *International Journal of Tropical Insect Science, 21*, 375-380

Khan, Z.R., Midega, C.A.O., Pittchar, J.O., Murage, A.W., Birkett, M.A., Bruce, T.J.A., & Pickett, J.A. (2014). Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. *Philosophical Transactions of the Royal Society B, 369,* 20120284

Kiritani, K. (2013). Different effects of climate change on the population dynamics of insects. *Applied Entomology and Zoology, 48,* 97-104

Li, Z., Zalucki, M. P., Yonow, T., Kriticos, D. J., Bao, H., Chen, H., … Furlong, M. J. (2016). Population dynamics and management of diamondback moth (*Plutella xylostela*) in China: The relative contributions of climate, natural enemies and cropping patterns. *Bulletin of Entomological Research, 106*, 197-214

Liebhold, A. M., Work, T. T., McCullough, D. G., & Cavey, J. F. (2006). Airline baggage as a pathway for alien insect species invading the United States. *American Entomology, 52,* 48-54

Luck, J., Spackman, M., Freeman, A., Trebicki, P., Griffiths, W., Finlay, K., & Chakraborty, S. (2011). Climate change and diseases of food crops. *Plant Pathology, 60*, 113-121

Macfadyen, S., Mcdonald, G., & Hill, M. P. (2016). From species distribution to climate change adaptation: knowledge gaps in managing invertebrate pests in broad-acre grain crops. *Agriculture, Ecosystems & Environment* (In Press

Machekano, H., Mvumi, B. M., & Nyamukondiwa, C. (2017). Diamondback moth, *Plutella xylostella* (L.) in southern Africa: Research trends, challenges and insights on sustainable management options. *Sustainability, 9*, 1-23

Mampholo, B. M., Sivakumar, D., & Thompson, A. K. (2016). Maintaining overall quality of fresh traditional leafy vegetables of Southern Africa during the postharvest chain. *Food Reviews International, 32,* 400-416

Maran, A. M., & Pelini, S. L. (2016). *Insect communities. Climate Change* (2nd ed., pp. 153-166), Elsevier B.V

Mazzi, D., & Dion, S. (2012). Movement of insect pests in agricultural landscapes. *Annals of Applied Biology, 160*, 97-113

Mboup, M., Bahri, B., Leconte, M., De Vallavieille-Pope, C., Kaltz, O., & Enjalbert, J. (2012). Genetic structure and local adaptation of European wheat yellow rust populations: The role of temperature adaptation. *Evolutionary Applications, 5*, 341-352

Meisner, M. H., Harman, J. P., & Ives, A. R. (2014). Temperature effects on long-term population dynamics in a parasitoid-host system. *Ecological Monographs, 84*, 457-476

Mendelsohn, R. (2008). The impact of climate change on agriculture in developing countries. *Journal of Natural Resource Policy Research, 1*, 5-19

Mirza, M. M. Q. (2011). Climate change and extreme weather events: Can developing countries adapt? *Climate Policy, 3*, 233-248

Musolin, D. L., Tougou, D., & Fujisaki, K. (2009). Too hot to handle? Phenological and life history responses to simulated climate change of the southern green stink bug *Nezara viridula* (Heteroptera: pentatomidae). *Global Change Biology, 16*, 73-87

Newman, J. A. (2003). Climate change and cereal aphids: The relative effects of increasing CO_2 and temperature on aphid population dynamics. *Global Change Biology, 10*, 5-15

Ngowi, A. V., Maeda, D. W., & Partanen, T. J. (2007). Knowledge, Attitudes and Practices (KAP) among agricultural extension workers concerning the reduction of the adverse impact in agricultural areas in Tanzania. *Crop Protection, 26*, 1617-1624

Northstone, K., Joinson, C., Emmett, P., Ness, A., & Paus, T. (2011). Are dietary patterns in childhood associated with IQ at 8 years of age? A population-based cohort study. *Epidemiology and Community Health, 66*, 624-628

Nyamukondiwa, C., Weldon, C. W., Chown, S. L., leRoux, P. C., & Tereblanche, J. S. (2013). Thermal biology, population fluctuations and implications of temperature extremes for the management of two globally significant insect pests. *Journal of Insect Physiology,* 59, 1199-1211

Nyirenda, S. P., Sileshi, G. W., Belmain, S. R., Kamanula, J. F., Mvumi, B. M., Sola, P., … Stevenson, P. C. (2011). Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Northern Malawi and Eastern Zambia. *African Journal of Agricultural Research, 6*, 1525-1537

Nopsa, J. F. H., Thomas-Sharma, S., & Garrett, K. A. (2014). Climate change and plant disease. *Encyclopedia of Agriculture and Food Systems, 2*, 232-243.

Olabemiwo, F. A., Danmaliki, G. I., Oyehan, T. A., & Tawabini, B. S. (2017). Forecasting CO_2 emissions in the Persian Gulf States. *Global Journal of Environmental Science Management, 3*, 1-10

Obopile, M., Munthali, D. C., & Matilo, B. (2008). Farmers' knowledge, perceptions and management of vegetable pests and diseases in Botswana. *Crop Protection, 27,* 1220-1224

Ojiewo, C., Keatinge, D. J. D. H., Hughes, J., Tenkouano, A., Nair, R., Varshney, R., … Silim, S. (2015). The Role of Vegetables and Legumes in Assuring Food, Nutrition, and Income Security for Vulnerable Groups in Sub-Saharan Africa. *World Medical & Health Policy, 7,* 3

Olson, A. J., Pataky, J. K., D'Arcy, C. J., & Ford, R. E. (1990). Effects of drought stress and infection by Maize dwarf mosaic virus in sweet corn. *Plant Disease, 74,* 147-151

Palumbo, J. C., & Natwick, E. T. (2010). The bagrada bug (Hemiptera: Pentatomidae): A new invasive pest of cole crops in Arizonia and Carlifonia. *Plant Health Progress*

Paini, D. R., Sheppard, A. W., Cook, D. C., DeBarro, P. J., Worner, S. P., & Thomas, M. B. (2016). Global threat to agriculture from invasive species. *PNAS, 113,* 7575-7579

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*, 37-42

Patel, S., Yadar, S. K., & Singh, C. P. (2017). The incidence of painted bug, *Bagrada hilaris* (Burmeister) of *Brassica* spp and *Eruca sativa* with respect to the date of sowing. *Journal of Entomology and Zoology Studies*, *5*, 774-776

Pellegrino, A. C., penaflor, M. F. G. V., Nardi, C., Bezner-Kerr, W., Guglielmo, C. G., Bento, J. M. S., & McNeil, J. N. (2013). Weather forecasting by insects: Modified sexual behaviour in response to atmospheric pressure changes. *PLoS ONE, 8*, e75004

Pannga, I. B., Hanan, J., & Chakraborty, S. (2013). Climate change impacts on plant canopy architecture: Implications for pest and pathogen management. *European Journal of Plant Pathology, 135,* 596-610

Pulatov, B., Hall, K., Anderson, M., & Jonsson, A. M. (2014). Effect of climate change on the potential spread of the Colorado potato beetle in Scandinavia: An ensemble approach. *Inter-Climate Research, 62*, 15-24

Reed, D. A., May, C., Lewis, T., & Perring, T. M. (2011). *Effects of temperature and host plant on development, fecundity and longetivity of the stink bug, Bagrada hilaris*. Poster presented at the 59th annual meeting of the Entomological Society of America, November 13-16, 2011

Reed, D. A., Palumbo, J. C., Perring, T. M., & May, C. (2013). *Bagrada hilaris* (Hemiptera: Pentatomidae) an invasive stink bug attacking Cole crops in the south-western united States. *Journal of Integrated Management, 4*, 1-7

Reddy, G. V., Shi, P., Hui, C., Cheng, X., Ouyang, F., & Ge, F. (2015). The seesaw effect of winter temperature change on the recruitment of cotton bollworms *Herlicoverpa amigera* through mismatched phenology. *Ecology and Evolution, 5*, 5652-5661

Reddy, P. P. (2013). Impact of climate change on insect pests, pathogens and nematodes. *Pest Management in Horticultural Ecosystems, 19*, 225-233

Rejmanek, M., & Richardson, D. M. (2000). What makes some conifers more invasive? *Proceeding of the fourth international conference* (In Press)

Rosenzweig, C., Iglesias, A., Yang, X. B., Epstein, P. R., & Chivan, E. (2001). Climate change and extreme weather events: Implications for food production, plant diseases and pests. *Global Change & Human Health, 2*, 90-104

Ryan, G. D., Emiljanowicz, L., Harri, S. A., & Newman, J. A. (2014). Aphid host-plant genotype × genotype interactions under elevated co_2. *Ecological Entomology, 39*, 309-315

Saccaggi, D. L., Karsten, M., Robertson, M. P., Kumschick, S., Somers, M. J., Wilson, J. R. U., & Terblance, J. S. (2016). Methods and approaches for the management of arthropod border incursions. *Biological Invasions, 18*, 1057

Sharma, H. C., & Prabhaka, C. S. (2014). Impact of climate change on pest management and food security. *Integrated pest Management* (pp. 23-36). Academic Press, Elsevier, London, UK

Sparks, T. H., Dennis, R. L. H., Croxtron, P. J., & Cade, M. (2007). Increased migration of Lepidoptera linked to climate change. *European Journal of Entomology, 104*, 139-143

Singh, H., Malik, V. S. (1993). Biology of painted bug (*Bagrada cruciferarum*). *Indian Journal of Agricultural Science, 63*, 672-674

Sujay, Y. H., Sacatagi, H. N., & Patil, R. K. (2010). Invasive alien insects and their impact on agroecosystem. *Karnataka Journal of Agricultural Sciences, 23*, 26-34

Tenkouano, A. (2011). The Nutritional and Economic Potential of Vegetables. *State of the World's Food and Agriculture 2011: Innovations that Nourish the Planet* (pp. 27-38). New York: W. W. Norton & Company

Thompson, S., Levin, S., & Rodriguez-Iturbe, I. (2013). Linking plant disease risk and precipitation drivers: A dynamical systems framework. *The American Naturalist, 181*, 1-16

Trebicki, P., Nancarrow, N., Cole, E., Bosque-Perez, N. A., Constable, F. E., Freeman, A. J., … Fitzgerald, G. J. (2015). Virus disease in wheat predicted to increase with a changing climate. *Global Change Biology, 21*, 3511-3519

TsChirley, D., Muendo, K.V., & Weber, M.T. (2004). Improving Kenya's Domestic Horticultural Production and Marketing System: Current Competitiveness, Forces of Change, and Challenges for the Future (Volume II: Horticultural Marketing)". Working Paper 8b. Tegemeo Institute, Egerton University. Nairobi

Uusiku, N. P., Oelofse, A., Duodu, K. G., Bester, M. J., & Faber, M. (2010). Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: A review. *Journal of Food Composition Analysis, 23*, 499-509

Van Averbeke, W., Juma, K. A., & Tshikalange, T. E. (2007). Yield responses of African leafy vegetables to nitrogen, phosphorus and potassium: The case of *Brassica rapa* L. Subsp, *Chinensis* and *Solanum retroflexum* Dun. *Water SA, 33*, 355-362

VanDyck, H., Bonte, D., Puls, R., Gotthard, K., & Maes, D. (2014). The lost generation hypothesis: Could climate change drive ectotherms into a developmental trap? *OIKOS Synthesising Ecology, 124*, 54-61

Vanhanen, H., Veteli, T.O., Paivinen, S., Kellomaki, S., & Niemela, P. (2002). Climate change and range shifts in two insect defoliators: gypsy moth and nun moth- a model study. *Silva Fennica, 41,* 469

Van Jaarsveld, P. J., Faberand, M., & Van Heerden, I. (2012). Selected vitamin and mineral content of eight African leafy vegetables and their potential contribution to individual nutrient requirements. In A. Oelofse, & W. Van Averbeke (Eds.), *Nutritional Value and Water Use of African Leafy Vegetables for Improved Livelihoods; Water Research Commission TT535/12* (pp. 227-243). Water Research Commission, Pretoria, South Africa

Vassiliadis, S., Plummer, K. M., Powell, K. S., Trebicki, P., Luck, J. E., & Rochfort, S. J. (2016). The effect of elevated co_2 and virus infection on the primary metabolism of wheat. *Functional Plant Biology, 43,* 892-902

War, A. R., Paulraj, M. G., Ahmad, T., Buhroo, A. A., Hussain, B., Ignacimuthu, S., & Sharma, H. C. (2012). Mechanisms of plant defence against insect herbivores. *Plant Signal & Behaviour, 7*, 1306-1320

WHO. (2002). World Health Organisation. *Nutrition program: Micronutrient deficiency information system, iron deficiency anaemia*. Genera, Switzerland. Retrieved from http://www.who.int

WHO. (2013). World Health Organisation global database on vitamin A deficiency. Vitamin and Mineral Nutrition Information System (VMNIS). http://www.who.int/VMNIS/database/vitamin/en

Woodman, J. D. (2015). Surviving a flood: Effects of inundation period, temperature and embryonic development stage in locust eggs. *Bulletin of Entomological Research, 105*, 441-447

Yang, R. Y., & Keding, G. B. (2009). Nutritional contributions of important African indigenous vegetables. In C. M. Shackleton, C. M., Pasquini, M. W., & A. W. Drescher (Eds.), *African Indigenous Vegetables in Urban Agriculture* (Ch. 4, pp. 10-35). Earthscan, London

Zhang, W., Chang, X., Hoffmann, A., Zhang, S., & Ma, C. (2015). Impact of hot events at different developmental stages of a moth: The closer to adult stage, the less reproductive output. *Scientific Reports, 5*, 10436

Ziska, L. H., & Mcconnell, L. L. (2016). Climate change, carbon dioxide and pest biology: Monitor, mitigate, manage. *Journal of Agricultural and Food Chemistry, 64*, 6-12

CHAPTER 3: FARMER'S PERCEPTIONS AND KNOWLEDGE OF INSECT PESTS UNDER CLIMATE CHANGE

Abstract

Pests are problematic in vegetable and field crop production in Limpopo Province. Limpopo Province experiences extreme heat waves, droughts and erratic rainfall accompanied by high temperatures. This study-evaluated farmer's perception and knowledge of major pests of vegetable and field crops under climate change in Limpopo Province. Data was collected using quantitative and qualitative participatory methods. One hundred and sixty-three smallholder farmers participated in survey data collection. The study showed that maize and sweet potato were major crops grown by dryland system farmers. Cabbage, mustard spinach, black nightshade and tomatoes were major crops grown by irrigated system farmers. Aphids were major pests in all municipalities compared to other insect pests ($P < 0.05$). The highest percentage of aphids was found in Mutale (82.1%) and the lowest in Thulamela (66.7%). Red spider mite was significantly higher in Musina municipality (82.1%) and was significantly different from the rest of the municipalities. Mobility of insect pests was significantly highest in Thulamela dryland system (70.4%) than all the municipalities and landuse ($P < 0.05$). The lowest percentage of insect pest mobility was found in Mutale dryland system (17.9%). Farmers also identified fall armyworm, diamondback moth, cutworm, bagrada bug as other major insect pests causing yield loss in vegetables and field crops. It can be perceived that types of crops grown and climatic conditions in Limpopo Province influenced the spread and distribution of these pests. There is need for farmers to be trained on the behaviour of insect pests under climate change.

Key words: Pest behavior, vegetables, field crops, physical appearance, increased temperature

3.1. Introduction

Smallholder farmers growing crops in developing countries encounter constraints such as transportation, acess to markets to sell their produce, pests and diseases. Amongst these constraints, pests and diseases are the major problems to vegetable and field crop production (Ojo et al., 1997).

Insects alone account for 18% loss of crops, while diseases account for 16% respectively (Oerke, 2006). Insect pest damage can result into ± 25 million tons of food loss, which may result in food insecurity (Oliveira et al., 2014). Smallholder farmers in develoing countries who grow vegetables all year round, in both dryland and irrigated systems, identified pests and diseases as major problems to their crops (Ojo et al., 1997). The damage caused by pests and diseases result to reduced harvest, increased production costs and reduced income due to reduced crop markets (Ojo et al., 2007). Crop loss has been increasing for the last 40 years because of pest damage (Oerke, 2006).

Most smallholder farmers have adopted the use of chemicals to manage insect pests and diseases in vegetable production. This has resulted to an increase in pesticide reliance and thus increasing pesticide resistance (Jallow et al., 2017). The overuse of pesticides can also lead to health problems and can impact the environment if not handled properly. Pesticides can be harmful to soil organisms such as macrofauna, which are known as soil engineers, and are essential for soil organic matter.

It is important for farmers to have knowledge about insect pests damaging their crops and how they are supposed to control them. Farmer's beliefs, preferences and perceptions can affect their attitudes towards pest management strategies. Garming and Waibel, (2007) reported that pesticides poisoning has resulted in change in farmer's attitudes and has influenced the increase in integrated pest management testing to manage pests. Farmer's perception on agricultural practices is highly influenced by socio-economic characteristic and perceptions differ from farmer to farmer (Tatlidil et al., 2009).

Studies have been done to evaluate farmer's knowledge and understanding on pests and diseases in African countries such as Cameroon (Okolle et al., 2016). However, very few studies have been conducted on evaluating farmer's perceptions on climate change and its impact on insect pests and diseases. Insect pests such as grasshoppers, beetles and caterpillars have been indicated by farmers to be major serious pests resulting in fruit vegetable loss in

Nigeria (Olaniran, et al., 2014). Most farmers in Africa grow vegetables such as tomatoes, cabbages, okra and mustard spinach and indigenous vegetables (Nyirenda et al., 2011) and therefore it is important that they must know the insect pests and the level of damage they can cuase on their crops. The majority of farmers in Zambia have confirmed that insect pests are major pests that result in severe crop yield loss compared to weeds and diseases (Nyirenda et al., 2011).

There is little knowledge of perceptions on climate change, insect pests and diseases constraining vegetable production of smallholder farmers in South Africa. Therefore, this study was done to evaluate the knowledge of smallholder farmers on climate change, impact of climate change and identification of insect pests on vegetable and field crop production in rural areas of Limpopo province. The objectives of this study were:

- To determine farmer's perception of climate change and variability
- To determine the relationship between changes in climate and incidence of insect pests
- To evaluate farmer's perception and knowledge of insect pest.

3.2. Materials and methods

3.2.1. Description of study site

The study was conducted in South Africa, Limpopo Province in four municipalities of Vhembe District (22.7696^o S, 29.9741^o E). Vhembe District constitutes of four municipalities, which are Mutale (22.5108^o S, 30.8039^o E), Thulamela (22.8922^o S, 30.6200^o E), Makhado (23.0462^o S, 29.9047^o E) and Musina (22.3953^o S, 29.6963^o E). Within the district is Musina municipality, which shares a border with Zimbabwe through the Beit bridge gate (Brournels, 2014). The population in this district is about 68.359 and the majority of this population number are black people (Stats, 2011). Vhembe district is characterized by semi-arid climates and it experiences dry spells with high temperatures throughout the year (Mpandeli, 2006). In some areas such as Musina municipality, rainfall ranges around 372 mm in summer seasons (Mpandeli, 2006) whereas rainfall is about 137 mm in Mutale municipality (Brournels, 2014). This district was chosen because it is known to experience high temperatures and erratic rainfall. This means that farmers in these areas are more vulnerable to climatic changes. Vegetables such as tomatoes, cabbages, black nightshade and mustard spinach are the common vegetables grown in this district. These vegetables are mostly grown in areas ranging from 1 hectare and above. Maize and sweet potatoes are the main field crops grown in Vhembe District. The most methods used for irrigation are drip and furrow irrigation for those who have access to water. In most of these municipalities, vegetables are rotated with field crops occasionally.

3.2.2. Study approach

Sampling concentrated on smallholder farmers found in rural areas and in peri-urban areas. Hundred and sixty-three farmers were selected randomly from a list of household farmers provided by extension officers. Quantitative data was collected using questionnaires. Qualitative data was collected through focus group discussions and key informants. Three focus groups were conducted in each municipality. This consisted of seven women alone, seven men alone and a combined group of seven men and seven women. Seven women and seven men were randomly selected from a list of farmers who did not participate in the questionnaire. Key informants selected in each municipality were extension officers and old age farmers familiar with the municipality. A checklist was used to collect qualitative data from key informants and focus group.

3.2.3. Data analysis

The data was encoded in Statistical Package for Social Sciences (SPSS) 23. Chi-square was used to compare the differences between different variables. Means and significant differences between means were declared at $P \leq 0.05$.

3.3. Results

Farmers in dryland systems knew fall armyworm, stalk borer and armoured bush cricket as the major pests of maize crops (Table 3.1). Sweet potatoes were attacked by sweet potato weevils. In all municipalities, farmers mentioned aphids as the major pest to cabbages. However, Thulamela municipality farmers also mentioned snails and whitefly, while Makhado municipality farmers mentioned cutworm and diamondback moth as major pest of cabbages. Mutale municipality and Makhado municipality farmers perceived blister beetles as problematic pest of green beans. However, Thulamela farmers only mentioned aphids as green bean pests. All municipalities mentioned aphids as pests to black nightshade and mustard spinach crops. All municipalities also indicated that bagrada bug is a pest to mustard spinach crop. Red spider mite was mentioned to be a tomato pest in Thulamela municipality and Mutale municipality. Mutale farmers further mentioned aphids and whiteflies to be problematic pests of tomatoes.

Table 3.1: Pest of major crops of dryland systems in municipalities

Dryland system municipalities			
Crop	**Thulamela**	**Mutale**	**Makhado**
Maize	Fall armyworm, Stalk borer	Stalk borer, fall armyworm	Armored bush cricket, stalk borer, fall armyworm
Sweet potato	Sweet potato weevil	Crop not grown	Ants, sweet potato weevil, rats
Cabbage	Snail, aphids, whitefly	Whitefly, aphids, snail, cutworm	Diamondback moth, aphids, cutworm
Green beans	Aphids	Blister beetles	Blister beetles
Black nightshade	Aphids	Aphids, whitefly	Locusts, aphids
Mustard spinach	Bagrada bug, aphids	Bagrada bug, aphids, snail	Bagrada bug, aphids
Tomatoes	Red spider mite	Red spider mite, whiteflies, aphids	

In irrigated systems, fall army worm was mentioned to be a problematic insect pest in all municipalities except Musina municipality. Stalk borer was problematic in Thulamela and Mutale municipalities. Makhado farmers also mentioned armoured bush cricket as one of the insect pest to maize crops. Sweet potatoes were attacked by sweet potato weevil in Thulamela and Makhado municipalities (Table 3.2). However, Thulamela municipality farmers also mentioned tortoise beetle, while Makhado municipality farmers mentioned ants and rats as sweet potato pests. With respect to cabbage, aphids were regarded as problematic pests in all municipalities that grew cabbages. Aphids in Thulamela municipality attacked green beans while blister beetles and rats attacked green beans in Makhado municipality. Black nightshade was attacked by aphids across all municipalities except in Musina municipality. Mustard spinach was attacked by bagrada bug and aphids in all municipalities that grew the crop. However, cutworm and snails were also mentioned to be problematic to mustard spinach in Mutale municipality. In Musina municipality, tomatoes were attacked by whitefly, South American tomato pinworm, leafminer, looper and red spider mite (Table 3.2). Okra was attacked by aphids and tuber moths while watermelon was attacked by fruit flies and aphids in Musina municipality.

Table 3.2: Pests of major crops of irrigated system in municipalities

	Municipality			
Crop	**Thulamela**	**Mutale**	**Makahdo**	**Musina**
Maize	Stalk borer, fall armyworm	Stalk borer, fall armyworm	Armored bush cricket, fall armyworm, rats	Crop not grown
Sweet potato	Weevil, tortoise beetle	Crop not grown	Ants, rats, sweet potato weevil	Crop not grown
Cabbage	Aphids, snails, whitefly	Diamondback moth, whitefly, snail	Diamondback moth, aphids, cutworm	Crop not grown
Green beans	Aphids	Crop not grown	Blister beetle, rats	Crop not grown
Black nightshade	Aphids	Aphids	Aphids, ants	Crop not grown
Mustard spinach	Bagrada bug, aphids	Bagrada bug, aphids, cutworm, snail	Bagrada bug, aphids	Crop not grown
Tomato	Crop not grown	Crop not grown	Crop not grown	Whitefly, South American tomato pinworm, Leafminer, looper, red spider mite
Okra	Crop not grown	Crop not grown	Crop not grown	Aphids, tuber moth
Watermelon	Crop not grown	Crop not grown	Crop not grown	Fruit fly, aphids

3.3.1. Insect pests across municipalities

Within dryland systems, Mutale and Makhado municipalities were not significantly different from each other with respect to aphid prevalence on crops ($P > 0.05$) (Figure 3.1). With respect to fall armyworm, Makhado municipality (50%) and Mutale municipality (39.3%) were not significantly different from each other but were significantly different from Thulamela municipality (25.9%). With respect to red spider mite and cutworm, Thulamela municipality (40.7%) was significantly different from Mutale municipality (25%) and Makhado municipality (14.3%) which did not show any significant difference. With respect to diamondback moth, Mutale municipality (53.6%) and Thulamela municipality (44.4%) were not significantly different from each other, but were significantly different from Makhado municipality (25%).

Within irrigated systems, with respect to fall armyworm, Mutale municipality (32.1%) and Thulamela municipality (14.8%) were significantly different from each other. However, Thulamela municipality (14.8%) and Musina muncipality (14.3%) did not show any significant deference from each other (Figure 3.1). All municipalities were not significantly different amongst each other with respect to aphids ($P > 0.05$). With respect to cutworm, Thulamela municipality (55.6%) was significantly different from the rest of municipalities which showed no significant difference amongst each other ($P < 0.05$). With respect to diamondback moth, Makhado (25%) was significantly different from the rest of the municipalities ($P < 0.05$). However, Musina (64.3%) was not significantly different from Thulamela municipality (55.6%) but significantly different from Mutale municipality.

Within municipalities, in Musina, red spider mite (82.1%) was significantly different from all insect pests except aphids (75%). In Makhado both irrigated and dryland, aphids were significantly different to the rest of the insect pests ($P < 0.05$). In Thulamela dryland system, whitefly (44.4%), diamondback moth (44.4%) and cutworm (51.9%) were not significantly different from each other but showed significant difference from beetles (22.2%), fall armyworm (25.9%) and bollworm (29.6%). In Mutale irrigated system, bollworm (3.6%), beetle (7.1%) and red spider mite (17.9%) were not significantly different from each other, but showed significant difference from the rest of the insect pests. In Mutale dryland, fall armyworm (39.3%) and red spider mite (25%) were not significantly different from each other but showed significant difference from the rest of the insect pests.

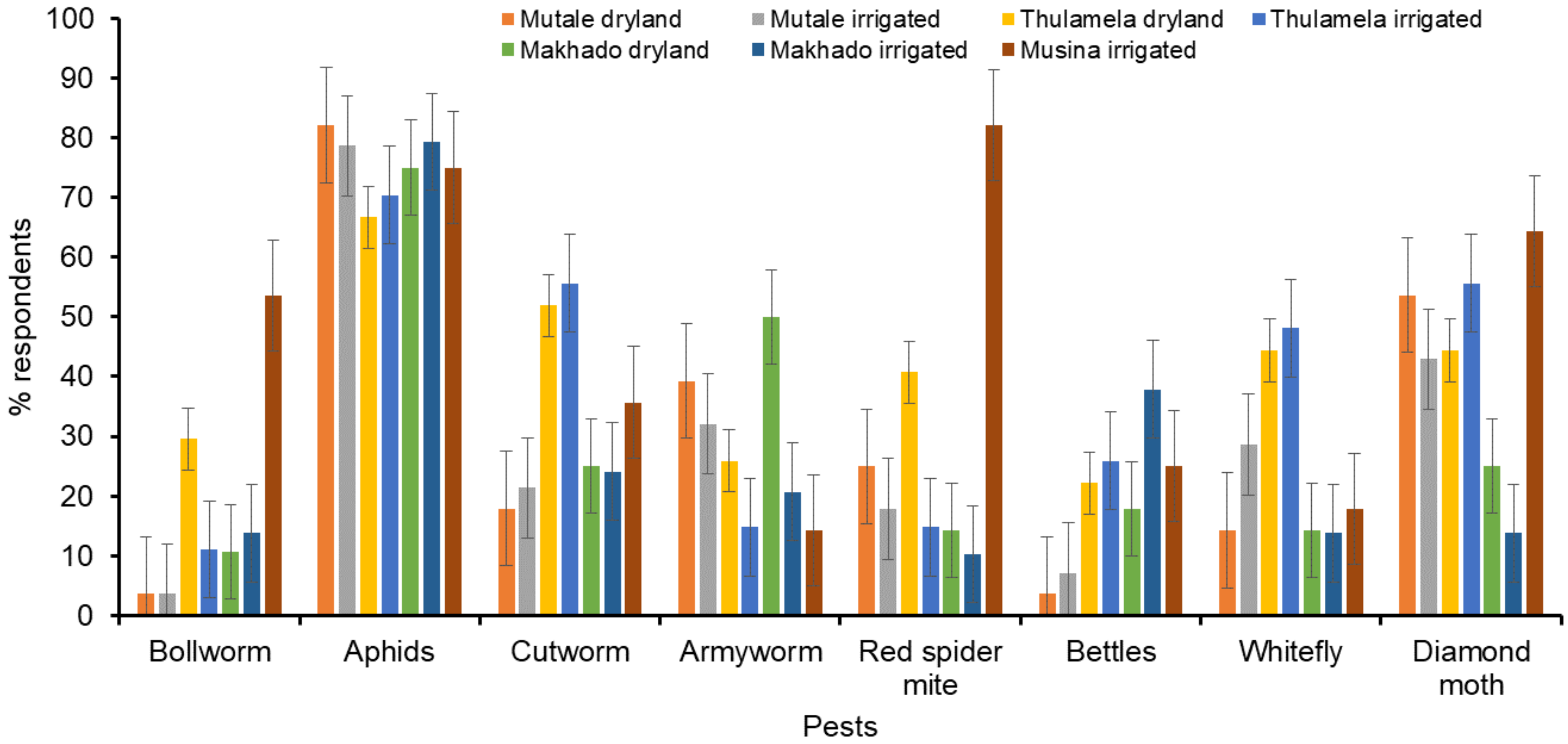

Figure 3.1: The most prevalent pests across municipalities and land use

Bars represent standard error (SE) of the mean

3.3.2. Farmer's perception on insect pest problem across municipalities

Increase in insect pests was significantly different to decreased insect pests and no change in all municipalities (P < 0.05) (Table 3.3). With respect to increased insect pests, Mutale dryland system (67.9%) and Makhado dryland system (64.3%) were not significantly different from each other, but showed significant difference from the rest of the municipalities. With respect to decrease in insect pest problems over the last ten years, all municipalities did not show significant difference from each other. With respect to no change, Makhado dryland (17.9%) was significantly different from the rest of the municipalities which did not show any significant difference amongst each other.

Table 3.3: Perception on insect pests problem across municipalities and landuse (% of respondents)

Level of incidence	Mutale		Thulamela		Makhado		Musina
	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Irrigated
Has increased	67.9b	82.1a	77.8a	85.2a	64.3b	79.3a	75a
Has decreased	7.1d	0	7.4d	0	3.6d	3.4d	7.1d
No change	10.7d	3.6d	0	0	17.9c	3.4d	3.6d
STDEV	34.11	46.40	42.94	49.19	31.73	43.82	40.25

Means followed by the same letter are statistically similar at $P \leq 0.05$

3.3.3. Farmer's perception on insect pest behavior

Within dryland systems, Makhado municipality (46.4%) was not significantly different from Thulamela municipality (51.9%) but was significantly different from Mutale municipality (67.9%) with respect to fast insect reproduction (Figure 3.2). With respect to pest crowding, Mutale municipality (32.1%) was significantly different from Thulamela municipality (7.4%) and Makhado municipality (17.9%) which were also significantly different from each other. With respect to increased mobility, Thulamela municipality (70.4%) was significantly higher than Mutale municipality (7.9%) and Makhado municipality (50%) which also showed significant difference amongst each other.

Within irrigated systems, Musina municipality (75%) and Mutale municipality (75%) were not significantly different from each other with respect to fast reproduction, but showed significant difference from Thulamela municipality (33.3%) and Makhado municipality 13.8%) (Figure 3.2). With respect to insects producing many eggs, Musina municipality (78.6%) was significantly different from all municipalities ($P < 0.05$). Thulamela municipality (40.7%) showed significant difference from Makhado municipality (58.6%) with respect to insects producing many eggs. With respect to increased mobility, Mutale municipality (25%) was significantly lower than the rest of the municipalities. Thulamela municpality (59.3%) and Makhado municipality (48.3%) were not significantly different from each other, but Thulamela municipality was significantly different from Musina municipality (42.9%).

Within municiapalities, fast reproduction was significantly higher than the rest of the factors in both dryland and irrigated system of Mutale municipality ($P < 0.05$). In both irrigated and dryland system of Thulamela municipality, increased mobility was significantly higher than the rest the factors. In Makado dryland system, insects producing many eggs was significantly higher than all the factors. Increased mobility (50%), fast reproduction (46.4%) and pests flying (46.4%) were not significantly different from each other in Makhado dryland system. In Musina municipality, fast reproduction (75%) and insects producing many eggs (78.6%) were not significantly different from each other but showed significance difference from the rest of the factors. In Makhado irrigated system, fast reproduction and pest crowding were not significantly different from each other, but were significantly different from the rest of the factors.

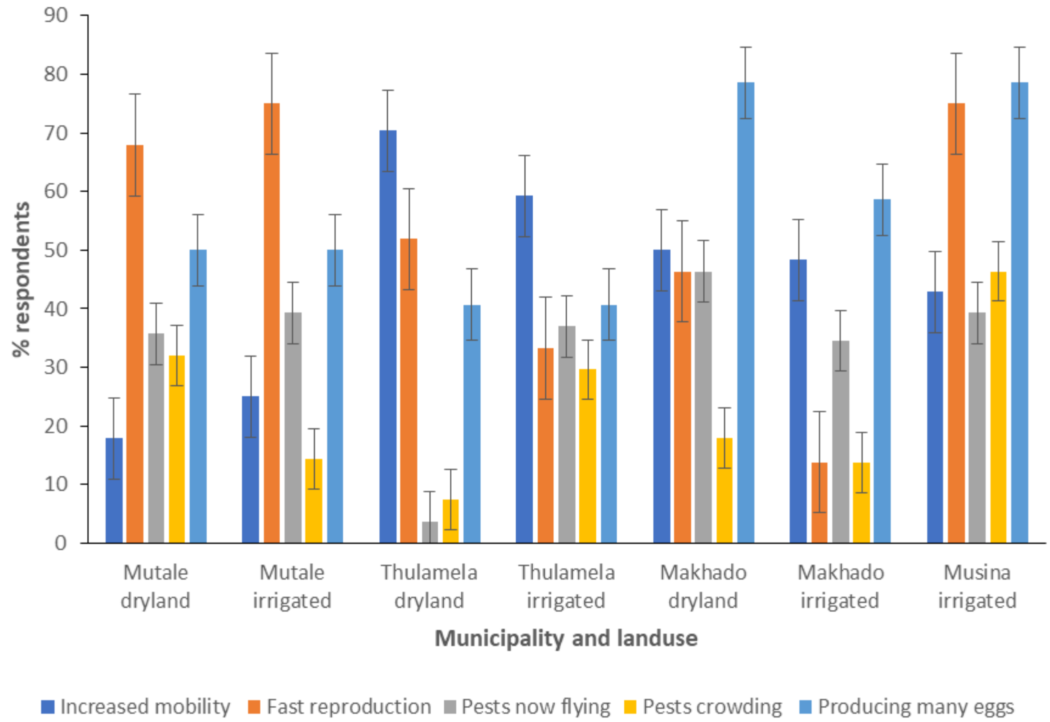

Figure 3.2: Farmer's perception on insect pest behaviour
Bars represent standard error (SE) of the mean

3.3.4. Famers' perception on insect physical appearance

Within dryland systems, development of colour variations in Mutale municipality (10.7%) was not significantly different from Thulamela municipality (7.4%) (P > 0.05) (Figure 3.3). Development of wings was not significantly different amongst all municipalities. Insect pests becoming darker was not significantly different between Mutale (14.3%) and Thulamela (14.8%) but showed significant difference from Makhado municipality (3.6%).

In irrigated systems, insects becoming lighter in color was not significantly different between Mutale municipality (14.3%) and Makhado municipality (13.8%) but significantly different from Musina municipality (3.6%) and Thulamela municipality (7.4%) (Figure 3.3). With respect to different colour variations, Thulamela municipality was significantly different from the rest of the municipalities. Insects becoming darker was significantly higher in Musina (21.4%) and was significantly different from the rest of the municipalities which did not show any significant difference from each other.

Within municipalities, in Musina, insects becoming darker was significantly different from the rest of the factors. In Makhado irrigated system, insects becoming darker (6.9%) was significantly different from the rest of the factors which did not show significant differences amongst each other. In Thulamela irrigated system, development of different colour variations (18.5%) was significantly different from insects becoming lighter (7.4%) and insects become darker (3.7%) and insects developing wings (11.1%). In Mutale irrigated system, insects becoming lighter was significantly different from the rest of the factors which were not significantly different from each other.

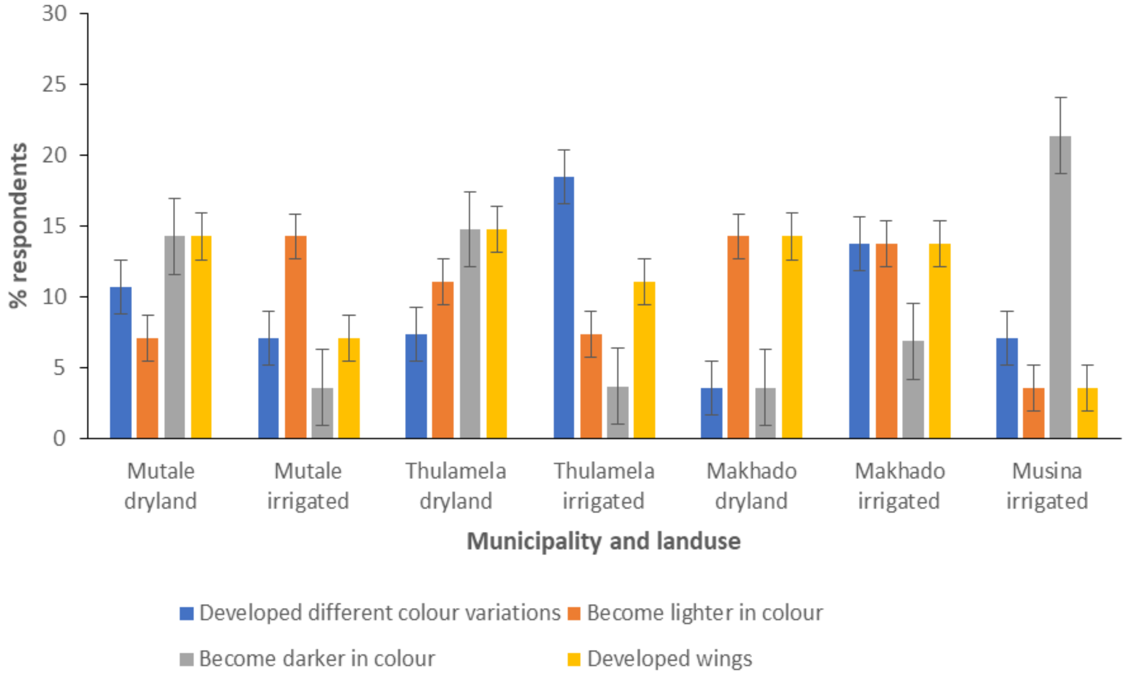

Figure 3.3: Farmer's perception on insect physical appearance
Bars represent standard error (SE) of the mean

3.3.5. Symptoms of insect pest's damage

Within dryland systems, Thulamela municipality (60.7%) and Makhado municipality (60.7%) were not significantly different from each other with respect to yellowing of leaves, but were significantly different from Mutale municipality (50%) (Figure 3.4). With respect to stunted growth, Makhado muncipality (46.4%) was significantly different from Thulamela municipality (18.5%) and Mutale municipality (35.7%) which were also significantly different from each other. With respect to leaf roll, Mutale municipality and Thulamela municipality were not significantly different from each other but were significantly different from Makhado municipality.

Within irrigated systems, Mutale, Musina and Thulamela municipalities were not significantly different from each other with respect to yellowing of leaves, but showed significantly difference from Musina municipality. With respect to leaf roll, Musina municipality (64.3%) and Thulamela municipality (63%) were not significantly different from each other but were significantly different from Makhado municipality (34.5%). With respect to stunted growth, Thulamela municipality (51.9%) was significantly different from Musina municipality (35.7%) and Mutale municipality (32.1%).

Within municipalities, yellowing of leaves was significantly different from the rest of the factors in Musina municipality. Stunted growth, blackening of veins and mottling were not significantly different from each other. In Makhado irrigated system, stunted growth was significantly higher than the rest of the factors. In Makhado dryland system, yellowing of leaves and stunted growth were significantly different from the rest of the factors. In Thulamela irrigated system, leaf roll and yellowing of leaves were not significantly different from each other but were significantly different from the rest of the factors. In Thulamela dryland system, yellowing of leaves and leaf roll were significantly different from each other and were also significantly different from the rest of the factors. In Mutale irrigated system, stunted growth and brown spots were not significantly different from each other but were significantly different from leaf roll and yellowing of leaves. In Mutale dryland system, leaf roll, stunted growth, brown spots and mottling were not significantly different from each other, but significantly different to yellowing of leaves.

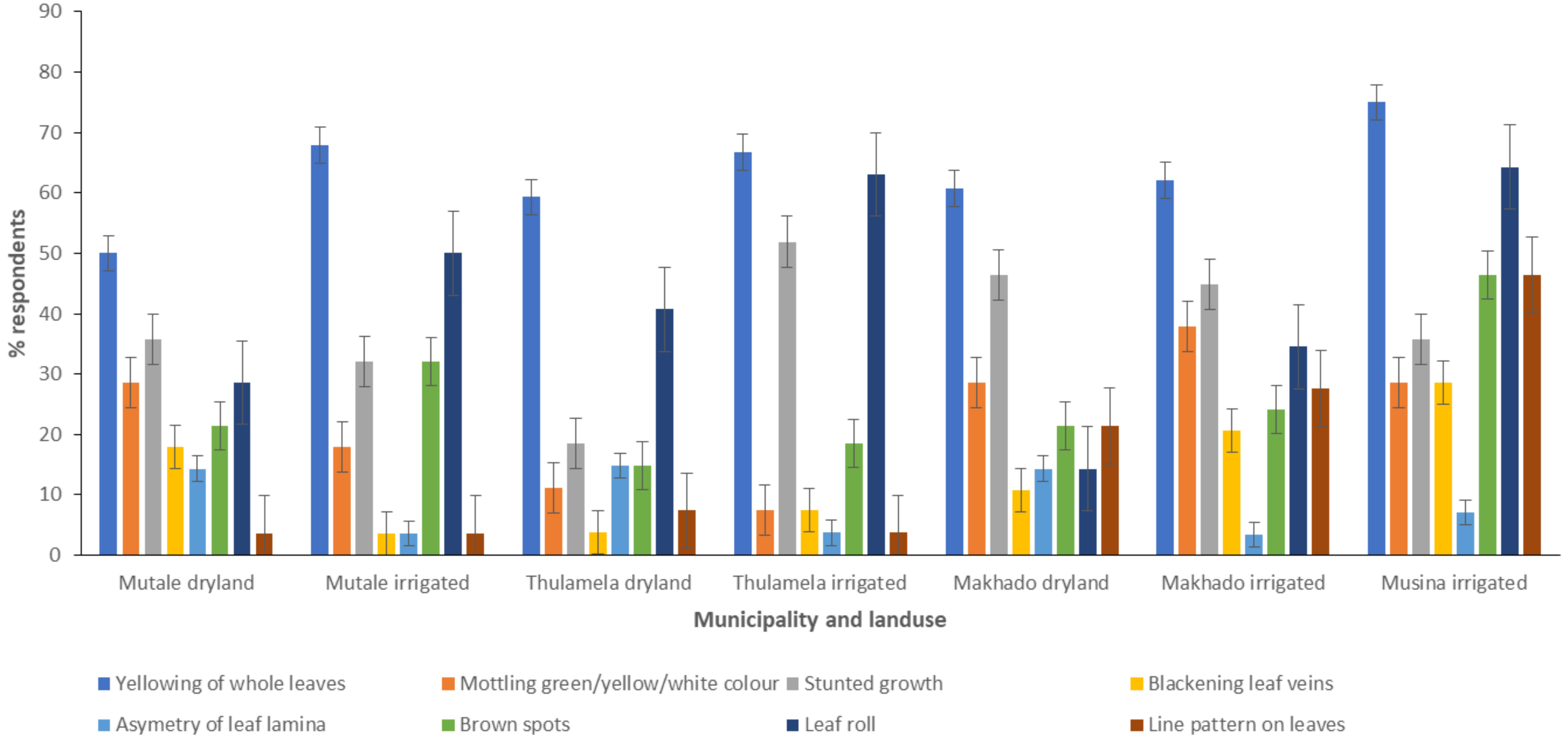

Figure 3.4: Farmer's perceptions on symptoms caused by insect pests

Bars represent standard error (SE) of the mean

3.3.6. Farmer's perception on aphid problem

Both dryland system (81.1%) and irrigated system farmers (82.1%) of Mutale municipality were significantly different from the rest of the municipalities and their land use with respect to farmers strongly agreeing that aphids were problematic pests on vegetables (Table 3.4). With respect to farmers agreeing that aphids are problematic pests, Musina municipality (14.3%), Makhado irrigated (65.5%) and dryland (60.7%) systems were not significantly different from each other but showed significant difference from Thulamela irrigated system (51.9%) and dryland system (25.9%) which showed significant difference amongst each other. With respect to neutral, there was not significant difference across municipalities.

Within municipalities, strongly agree was significantly different from the rest of the factors in all municipalities and landuse ($P < 0.05$). In Thulamela dryland system, agree (25.9%) and Neutral (11.1%) showed significant difference from each other. In both systems of Makhado municipalty, agree and neutral were not signifcanlty different from each other. In Musina municipality, neutral (7.1%) and agree (14.3%) did not show significant difference from each other.

Table 3.4: Farmer's perception on aphid problems

	Mutale dryland	Mutale irrigated	Thulamela dryland	Thulamela irrigated	Makhado dryland	Makhado irrigated	Musina irrigated
Strongly agree	82.1a	82.1a	48.1b	33.3c	60.7b	65.5b	60.7b
Agree	0	0	25.9c	51.9b	7.1d	10.3d	14.3d
Neutral	0	3.6d	11.1d	0	17.9d	6.9d	7.1d
Disagree	0	0	0	0	0	3.4d	3.6d
Strongly disagree	0	0	0	0	0	0	0
STDEV	35.72	36.35	20.37	24.24	25.43	27.26	24.92

Means followed by the same letter are statistically similar at $P \leq 0.05$

3.3.7. Aphid prevalence on crops

Within dryland systems, Thulamela municipality was significantly different from the rest of the municipalities with respect to aphid prevalence on mustard spinach (Figure 3.5). With respect to aphids on cabbages, Thulamela municipality (48.1%) was significantly higher in aphid prevalance than the rest of the municipalities. However, Makhado municipality (28.6%) and Mutale municipality (25%) were not significantly different from each other. With respect to aphid prevalence on tomatoes, Makhado municipality (35.7%) showed significant difference from Thulamela municipality (7.4%) and Mutale municipality (21.4%). Makhado municipality (21.4%) was significantly different from Mutale municipality (17.9%) and Thulamela municipality (7.4%) with respect to aphid prevalence on green beans.

Within irrigated systems, Thulamela municipality was significantly different from the rest of the municipalities with respect to aphids on mustard spinach. With respect to aphids on cabbages, Musina municipality (67.9%) was not significantly different from Thulamela municipality (22.2%) but was significantly different from the rest of the municipalities (Figure 3.5). Makhado municipality (55.2%) was significantly different from the rest of the municipalities with respect to aphid prevalence on green beans. However, Thulamela municipalty (22.2%) and Mutale municipality (17.9%) were not significantly different from each other. With respect to aphid prevalence on tomatoes, Musina municipality (60.7%) was significantly different from the rest of the municipalities. However, Makhado municipalty (31%) and Mutale municipalty (25%) were not significantly different from each other.

In Musina, tomatoes and cabbages were significantly different to each other with respect to aphid prevalence. In Makhado irrigated system, aphid prevalence on green beans were significantly higher than all the crops. However, sugar beans were not significantly different from tomatoes. In Makhado dryland system, tomatoes, maize and cabbages were not significantly different from each other but were significantly different from sugar beans and pepper pertaining to aphid prevalence. In Thulamela irrigated and dryland systems, cabbages and mustard spinach were not significantly different from each other but significantly different from the rest of the crops. In Mutale irrigated system, maize, tomatoes, cabbages, mustard spinach and green beans were not significantly different from each other but were significantly different from sugar beans and pepper. In Mutale dryland, spinach, tomatoes and cabbage were not significantly different from each other but were significantly different to sugar beans and sorghum as far as aphid infestation was concerned.

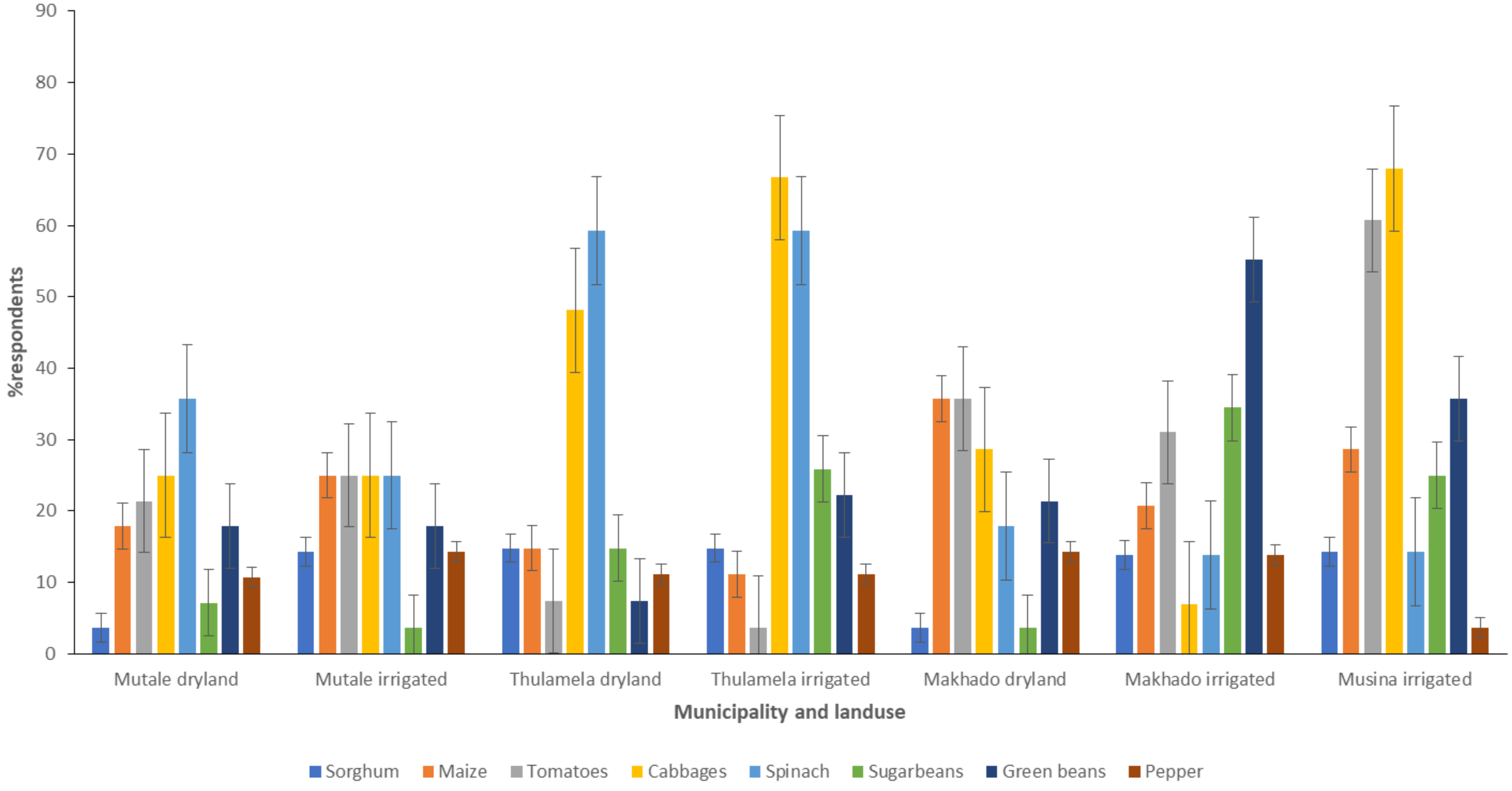

Figure 3.5: Aphids prevalence on crops

Bars represent standard error (SE) of the mean

3.3.8. Farmer's perceptions on aphid behavior

Within dryland systems, fast aphid reproduction was not significantly different between Makhado municipality (53.6%) and Thulamela municipality (59.3%) but was significantly different from Mutale municipality (75%) (Figure 3.6). Increased aphid mobility in Thulamela municipality (63%) was significantly different from Mutale municipality (32.1%) and Makhado muncipality (46.6%) which also showed significant difference amongst each other. With respect to aphids now flying, Mutale municipality (42.9%) was significantly different from Thulamela municipality (14.8%) and Makhado municipality (21.4%) which were not significantly different from each other.

Within irrigated systems, with resprct to fast aphid reproduction, Thulamela municipality (51.9%) was significantly different from Mutale muncipality (75%), Makhado muncipality (75.9%) and Musina municipality (75%) which did not show any significant difference amongst each other (Figure 3.6). With respect to increased aphid mobility, Musina municipality (42.9%) and Makhado municipality (44.8%) were not significantly different from each other but were significantly different from Thulamela (55.6%) and Mutale (28.6%) municipalities. With respect to aphids now flying, Thulamela municipality (22.2%) and Mutale municipality (10.7%) were not significantly different from each other, but were significantly different from Makhado municipality (3.4%) and Musina municipality (14.3%) which did not show any significant difference amongst each other.

In Musina, fast aphid reproduction was not significantly different from aphids crowding which showed significant difference from increased aphid mobility and aphids now flying. In Makhado irrigated system, fast aphid reproduction was significantly different from aphids crowding. In Thulamela irrigated and dryland systems, increased aphid mobility and fast aphid reproduction did not show any significant difference amongst each other but showed significant difference from the rest of the factors. In Mutale dryland and irrigated systems, fast aphid reproduction was significantly higher than the rest of the factors.

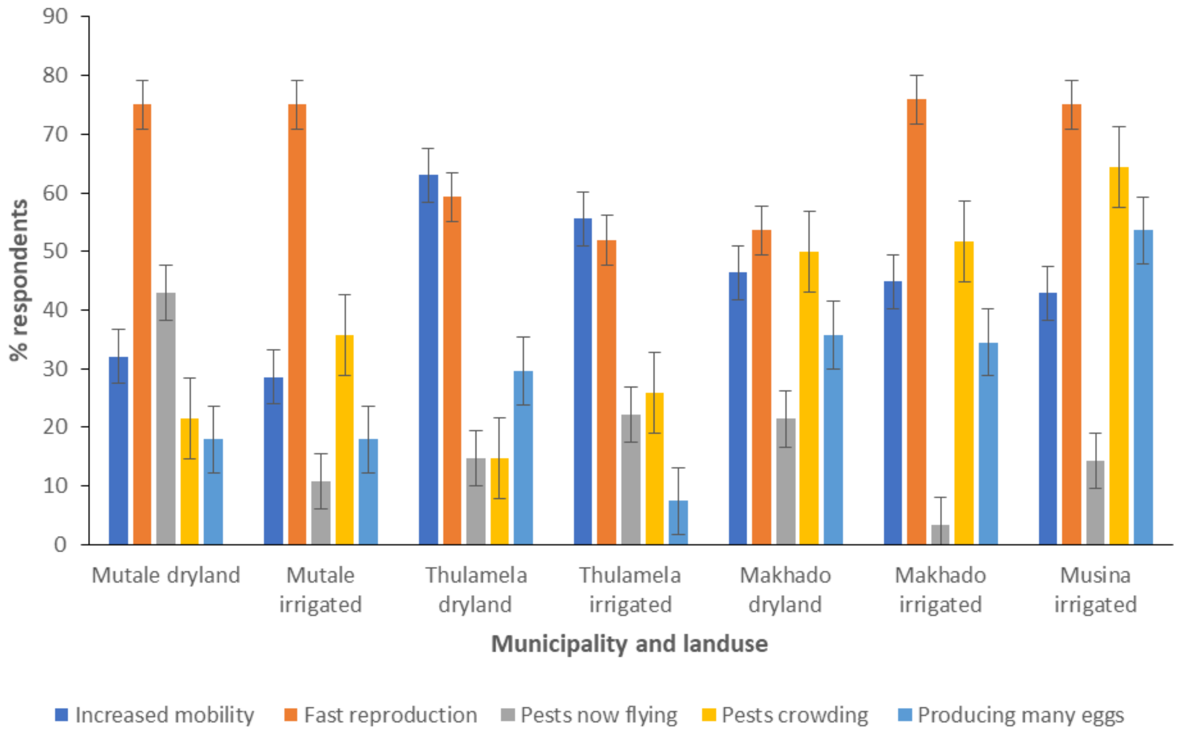

Figure 3.6: Farmer's perception on aphid behaviour
Bars represent standard error (SE) of the mean

3.3.9. Farmer's perception on aphid physical properties

Within dryland systems, aphids developing wings were not significantly different in all municipalities. Mutale municipality (14.3%) and Thulamela municipality (14.8%) were not significantly different from each other but showed significant difference from Makhado municipality (3.6%) with respect to aphids becoming darker (Figure 3.7).

Within irrigated systems, aphids becoming lighter in colour was not significantly different between Mutale municipality (14.3%) and Makhado municipality (13.8%) but was significantly different from Thulamela municipality (7.4%) and Musina municipality (3.6%). Aphids becoming darker was not significantly different between Mutale municipality (3.6%), Thulamela municipality (3.7%) and Makhado municipality (6.9%) but was significantly different from Musina municipality (21.4%) (Figure 3:7).

Within municipalities, in Thulamela dryland and irrigated systems, aphids developing different colour variations was significantly different from the rest of the factors. In Makhado dryland system, aphids becoming lighter and aphids developing wings were not significantly different from each other but showed significant difference from aphids developing different colour variations and aphids becoming darker, which did not show any significant difference from each other. In Musina municipality, aphids becoming darker was signifcanlty higher than the rest of the factors. In Mutale dryland system, aphids becoming lighter was signficanlty different from the rest of the factors.

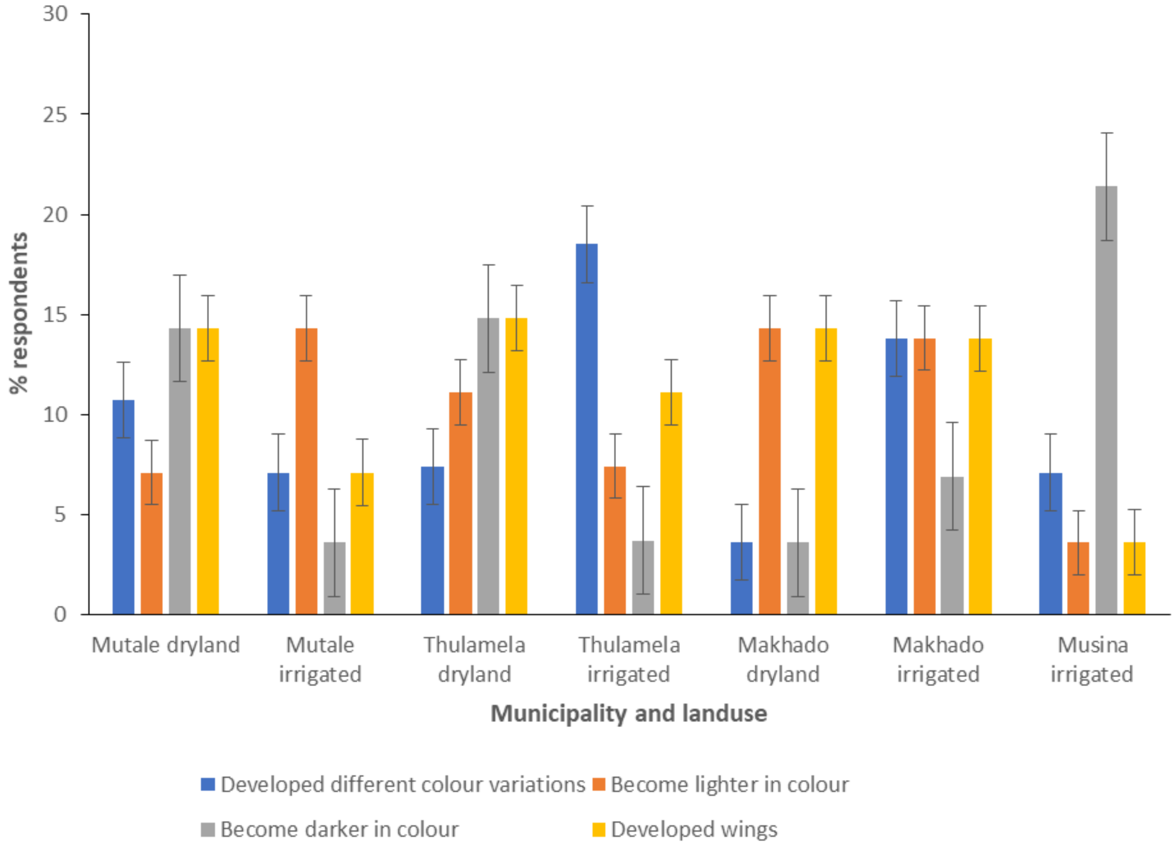

Figure 3.7: Farmer's perception on aphid physical properties
Bars represent standard error of the mean

3.3.10. Farmer's perception on symptoms caused by aphids

Within dryland systems, yellowing of vegetable leaves was not significantly different between Mutale municipality (57.1%) and Makhado municipality (50%) but was significantly different from Thulamela municipality (66.7%) (Figure 3.8). With respect to leaf roll of vegetables, Thulamela municipality (59.3%) was significantly different from Mutale municipality (39.3%) and Makhado municipality (42.9%) which did not show any significant difference from each other. With respect to stunted growth, Thulamela municipality (11.1%) was significantly lower than Mutale municipality (39.3%) and Makhado municipality (32.1%) which were not significantly different from each other.

Within irrigated systems, yellowing of vegetable leaves was not significantly different between Mutale (71.4%) and Makhado municipalities (75.9%) which were significantly different from Thulamela municipality (44.4%) and Musina municipality (64.3%). With respect to leaf roll, Thulamela municipality (63%) was significantly higher than the rest of the municipalities (Figure 3.8). Musina municipality (42.9%) and Makhado municipality (37.9%) were not significantly different from each other with respect to leaf roll but were significantly different from Mutale municipality. With respect to stunted growth, there was not significant difference amongst all municipalities.

Within municipalities, in Musina municipality and Makhado irrigated system, yellowing of leaves was significantly higher than all other factors ($P < 0.05$). In Makhado dryland system, leaf roll and yellowing of leaves were significantly different from the rest of the factors. In Thulamela irrigated system, leaf roll was significantly different from the rest of the factors. Stunted growth, mottling and yellowing of leaves were not significantly different from each other. In Thulamela dryland system, leaf roll and yellowing of leaves were not significantly different from each other but were significantly different from the rest of the factors. In Mutale irrigated and dryland systems, yellowing of vegetable leaves was significantly different from the rest of the factors.

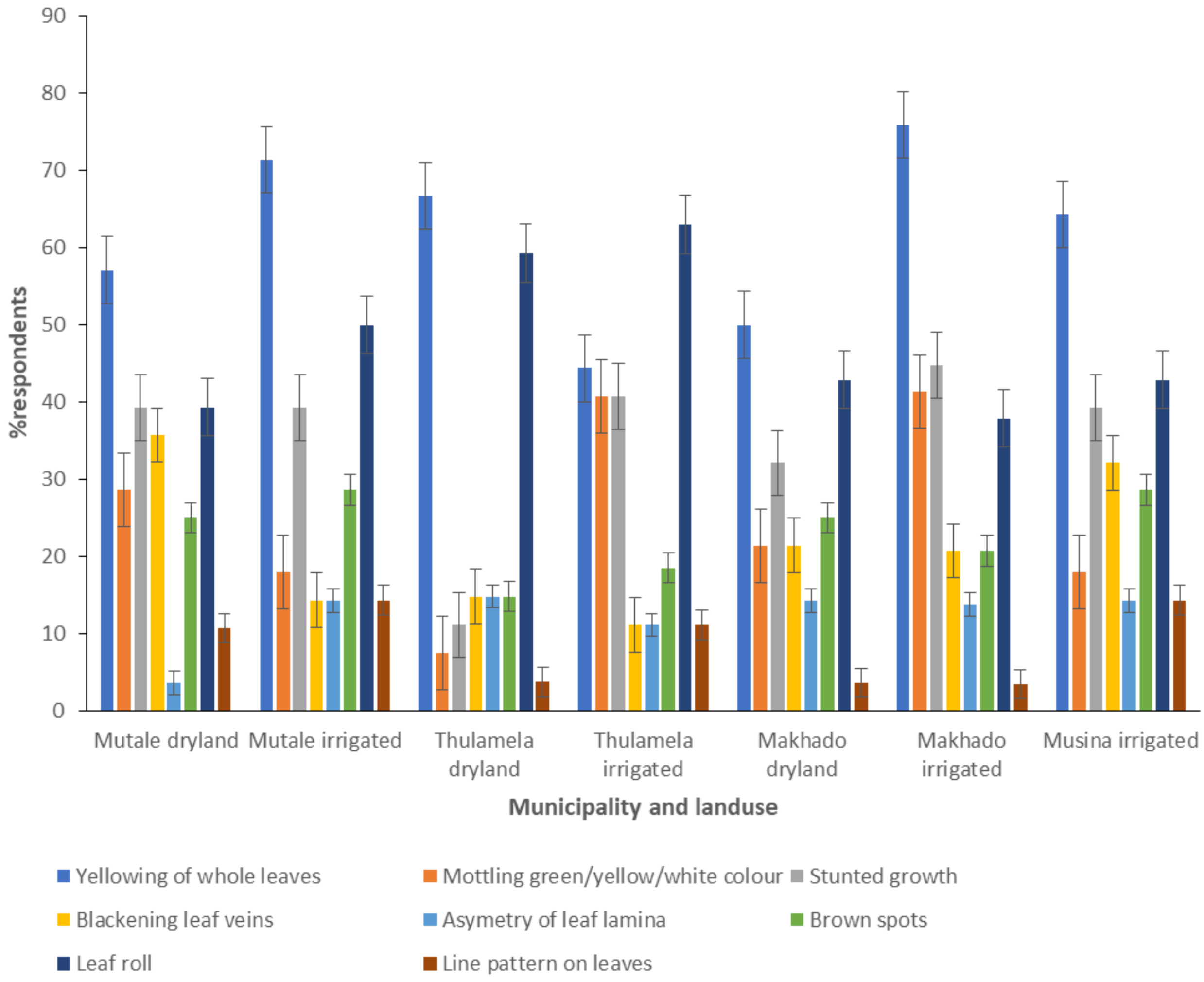

Figure 3.8: Farmer's perception on symptoms caused by aphids

Bars represent standard error (SE) of the mean

3.4. Discussion

This study has shown the major crops grown in dryland and irrigated systems of Limpopo Province. In dryland systems, the major crops grown were maize, sorghum and sweet potato. Farmers in dryland systems depended on rainfall when growing these field crops, which performed better than vegetables. However, vegetables were mostly grown in home gardens due to limited availability of water. Farmers in Limpopo Province experience summer rainfall (Tshiala, et al., 2012). This limits the growing of vegetables in winter season were there is no rainfall. Limpopo Province is said to have areas, which are potentially suitable for dryland crop production (Tshiala et al., 2012). In irrigated systems, the most grown vegetables were cabbages, tomatoes, black nightshade, and green beans. Farmers growing these crops depended on furrow irrigation, and these crops were grown all year round. Studies conducted in African countries such as Zambia and Malawi, which showed that farmers grew vegetables in both dry and wet seasons due to availability of water (Kuntashula et al., 2006; Mwandira, 2003). Farmers showed that they were able to identify insect pests damaging their crops. They also perceived how these pests damaged their crops. According to the results, aphids were the major insect pests in all municipalities. Aphids were problematic insect pests of green beans, tomatoes, okra, black nightshade and cabbage crops. Aphids highly adapt to high temperatures and can increase their developmental rate from temperatures starting from 27 ^{o}C and above (Meisner et al., 2014). Other major pests mentioned by farmers included diamondback moth, red spider mite, fall armyworm and cutworm. Diamondback moth (*Helicoverpa amigera*) has the ability to overwinter due to increased winter temperatures, and therefore increasing populations and resulting to significant damage on cabbage production (Reddy et al., 2015). Growing heat tolerant cabbages make them to be a perennial crop due to high temperatures in winter and summer seasons. This situation allows diamondback moth to be a prevalent pest on cabbages since the pest prefers high temperature environments (Kfir, 2003). Crop damage from diamondback moth can also result from high rates of insecticide resistance. This pest has shown to be resistant to synthetic pyrethroids, carbamates and organophosphates (Kfir, 2003). Red spider mite was a major pest of tomatoes and it was found highest in Musina municipality. The major crops widely grown in Musina municipality were tomatoes. Tomatoes were grown from one to 1000 hectares. According to Migeon et al (2009), red spider mite is an invasive pest in Africa and it is expected to expand throughout new regions of African countries. Other pests of tomatoes in Musina municipality included, loopers, leafminer, and the invasive South American tomato pinworm (*Tuta absoluta*).

Farmers agreed that insect pest problems have increased since they started farming. They reported that their yields were reduced. Olaniran et al (2014) reported that farmers in Nigeria had 65.4 % yield loss due to vegetable pests. Farmers reported new insect pests and they mentioned that minor insect pests were regarded as major problematic insect pests in the district. *Tuta absoluta* was reported for the first time in South Africa in 2016 (Visser et al., 2017) and fall armyworm was reported for the first time in early summer months of 2017. These new pests are expected to have arrived due to globalization and trade (Cock et al., 2017). However, due to their high adaptation rate to climate change, these pests have been observed and have resulted in huge damage to crops. Limpopo Province has been observed to be experiencing extreme weather events such as long-term droughts, increased temperatures and erratic rainfalls (LDA, 2012). Due to these events, farmers in Limpopo Province have observed high rates of pest population and new pest invasions (Ubisi et al., 2017).

Farmers also perceived the behavior of these problematic insect pests. Majority of farmers mentioned that pests have now increased their mobility, fast reproduction and relatively high production of many eggs. Global warming can affect insect population in a number of ways such as: changes in population growth rate, the increase in number of insect generations, the extension of geographical range, the introduction of species to alternative host plants, the increase of invasion risk by migrating insects and also overwintering of insects (Bale et al., 2002; Maran and Pelini, 2016). The increase in insect population numbers occurs when the growth and developmental rate of the insect has been increased. Short living insects that have adapted to high temperatures can be able to increase the number of generations in a year when influenced by warmer conditions (Van Dyck et al., 2014). Most insects usually move to the northern regions were they are able to disappear from unsuitable climatic conditions (Ziska and McConell, 2016; Pulator et al., 2016). Most of these insects that have high rates of migration are ectotherms and this type of insects is expected to continue shifting to higher latitudes and altitudes in the next decades (Vanhanen et al., 2007). It has been predicted that insects will shift by 6.1 km to the upward poles per decade due to increased temperatures (Parmesan and Yohe, 2003).

The majority of farmers in all municipalities agreed that aphids were problematic insect pests on vegetables. Most studies have reported that aphids are the most problematic insect pests on vegetable crops (Praveen and Dhandapani, 2002; Trionnaire et al., 2013). Farmers also indicated that aphids had increased their mobility and were reproducing relatively very fast.

High temperatures influenced the increase of *Aphidius ervi* found in peas. It increased the developmental rates of this aphid and the adult stage was found to be more tolerant to high temperatures thus resulting in severe pea damage (Meisner et al., 2014). Farmers also showed that aphids were now changing in physical appearance and color. In focus group discussions, farmers mentioned that aphids were known to be green in color. However, they were observing grey/black aphids on vegetables. This might be resulting from polyphenism influenced by changing environment and climatic changes. Aphids can be able to adapt to different environmental conditions, whereby the same genotype can produce different phenotypes as a way of maximizing its fitness (Halkett et al., 2006). Tobacco aphid (*Myzus persicae nicotiane)* was known to be green in Zimbabwe during 2002 and before. However, during 2003/2004 this aphid was now observed to be red in colour. The red morph was also found to be reproductive and survived longer than the green morphs (Masukwedza et al., 2013).

The majority of farmers perceived symptoms caused by aphids. Farmers observed leaf roll, stunted growth of crops and yellowing of leaves. During feeding, aphids can transmit variety of viruses (Brault et al., 2010), which are responsible for some of the disease symptoms associated with aphid infestation (Journamet et al., 2014). The damage caused by aphids often results in reduction in plant growth and development due to water stress and wilting (Jounamet et al., 2014). Aphids' feeding behaviour can be influenced by the availability of nitrogen in the plants. High amounts of nitrogen in the host crop can influence the abundance of aphids on the host plant (Rouseelin et al., 2016).

3.5. Conclusion

It has been shown in the study that the major crops grown in dryland systems were maize and sweet potatoes. The major crops grown in irrigated systems were tomatoes, cabbages, mustard spinach and black nightshade. Farmers showed that problematic insect pests include, fall armyworm, *Tuta absoluta*, diamondback moth, cutworm and caterpillars. Farmers also perceived the feeding behavior of major insect pests on their crops. According to the results, it can be concluded that climate change factors such as increased temperature, increased heat waves and drought frequency can influence the migration, behaviour and physical appearance of insect pests. The presence of new pests may have been highly influenced by globalization, people's movement and poor phytosanitary measures at borders. However, when these pests adapted to new climate, they potentially accelerated their population number and therefore increased severe threats to crop production. Little is known about the physical appearance of pest under the influence of climate change. There is need to conduct more studies on pest behaviour under climate change. There is also need to conduct more training of farmers on insect pests and their management under climate change. Phytosanitary measures at country borders should be improved to reduce entry of new insect pests in South Africa.

References

Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., Butterfield, J., Buse, A., Coulson, J.C., Farrar, J., Good, J.E.G., Harrington, R., Hartley, S., Jones, T.H., Lindroth, R.L., Hartley, S., Jones, T.H., Lindroth, R.L., Press, M.C., Symrnioudis, I., Watt, A.D, & Whittaker, J. H. (2002). Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Global Change, 8,* 1-16

Brault, V., Uzest, M., Monsion, B., Jacqout, E. & Blanc, S. (2010). Aphids as transport devices for plant viruses. *Comptes Rendus Biologies 333*, 524-538

Brournels, M. (2014). The local government handbook of South Africa 2014: a complete guide to municipalities in South Africa, 4th edistion. Yes! Media, Calermount, RSA, Pp. 2015

Cock, M.J.W., Beseh, P.K., Buddie, A.G., Cafa, G. & Crozier, J. (2017). Molecular methods to detect *Spodptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. *Scientific Reports, 7,* 4103

Gabriel, T. (1989). Pest control, pest management and the human factor. *Tropical Management, 35,* 254-256

Garming, H., & Waibel, H. (2007). Do farmers adopt IPM for health reasons? The case of Nicaruguan vegetable growers: proceedings of the Tropentag Conference Utilisation of diversity in Land Use Systems: Sustainable and Organic Approaches to meet human needs, 9-11, October 2007. Kassel, Germany

Halkett F, Kindlmann P, Plantegenest M, Sunnucks P., & Simon, J.C. (2006). Temporal differentiation and spatial coexistence of sexual and facultative asexual lineages of an aphid species at mating sites. *Journal of Evolutionary Biology, 19,* 809–815

Jallow, M. F. A., Awadh, D. G., Albaho, M. S., Devi, V. Y., & Thomas, B. M. (2017). Pesticide risk behaviours and factors influencing pesticide use among farmers in Kuwait. *Science of the Total environment, 574,* 490-498

Jaouannet, M., Rodiguez, P.A., Thorpe, P., Lenoir, C.J.G., MacLeaod, R., Escudero-Martinez, C. & Bos, J.I.B. (2014). Plant immunity in plant-aphid interactions. *Frontiers in Plant Science 5,* 1-10

Kang, M. S., & Bang, S. S. (2013). Global agriculture and climate change. *Journal of Crop Improvement, 27,* 667-692

Kfir, R. (2003). Biological control of the diamondback moth *Plutella xylostella* in Africa. In: Neusnschwander, P., Borgameister, C., Langewald, J. (eds) Biological control in IPM systems in Africa, CAB international, Wallingford, pp: 363-375

Kuntashula, E., Sileshi, G., Mafongonya, P.L., & Banda, J. (2006). Farmer participatory evaluation of the potential for organic vegetable production in the wetlands of Zambia. *Outlook Agronomy 35,* 299-305

LDA (2012): the mapping of agricultural commodity production in the Limpopo province, South Africa

Maran, A. M., & Pelini, S. L. (2016). Insect communities. Climate Change (2nd ed., pp. 153-166), Elsevier B.V.

Masukwedza, R., Mazarura, U., Chinwada, P., & Dimbi, S. (2013). The biology of the red and green morphs of Tobacco aphid, *Myzus persicae* Nicotianae (Blackman) on flue-cured Tobacco. *Asian Economic and Social Society, 3,* 2224-4433

Meisner, M. H., Harman, J. P., & Ives, A. R. (2014). Temperature effects on long-term population dynamics in a parasitoid-host system. *Ecological Monographs, 84,* 457-476.

Migeon, A., Ferragut, F., Escudero-Colomar, L.A., Fiaboe, K., Knapp, M., Gilberto, J., de Moraes, G.J., Ueckermann, E., & Navajas, M. (2009). Modelling the potential didtribution of the invasive tomato red spider mite, *Tetranchus evansi (*Acari:Tetranychidae). *Expl Appl Acarol, 48,* 199-212

Mpandeli, S.N. (2006). Coping with climate variability in Limpopo Province. Unpublished PhD thesis, University of Witwatersrand lessons from southern Africa. *South African Journal of Science, 105,* 34-49

Mwandira, C. (2008). The status of the vegetable industry in Malawi: current and future prospects. In: Chadha, M.L, Olouch, M.O, Saka, A.R, Mtukuso, A.P., Daud, A.T (eds) vegetable Research and Development in Malawi, AVRDC (The world vegetable center) AVRDC publication no: 08705

Nyirenda, S. P., Sileshi, G. W., Belmain, S. R., Kamanula, J. F., Mvumi, B. M., Sola, P., Nyirenda, G.K.C., & Stevenson, P. C. (2011). Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Northern Malawi and Eastern Zambia. African Journal of *Agricultural Research, 6,* 1525-1537

Oerke, E.C. 2006. Crop losses to pests. *Journal of Agricultural Science, 144,* 31-43

Okolle, N.J., Afari-Sefa, V., Bidogeza, J.,Tata, P.I., & Ngome, F.A. (2016). An evaluation of smallholder farmers' knowledge, perceptions, choices and gender perspectives in vegetable pests and diseases control practices in the humid tropics of Cameroon. *International Journal of Pest Management 62*, 165-174

Ojo, D.O., Olufalaji, A.O. (1997). *Gartenbauwissenschaft, 41*, 280-288

Olaniran, O.A., Babarinde, S.A., Odewole, A.F., Aremu, P.A., & Popoola, K. (2014). Rural farmer's perceptions, knowledge and management of insect pests of fruiy vegetables in Ogbomoso agricultural zone of Nigeria. *International Letters of Natural Sciences, 20,* 18-28

Oliveira, C.M., Auad, A.M., Mendes, S.M., & Frizzas, M.R. (2014). Crop losses and the economic impact of insect pests on Brazilian agriculture. *Crop Protection, 56,* 50-54

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature, 421*, 37-42

Praveen, P.M., & N. Dhandapani. (2002). Eco-friendly management of major pests of okra [*Abelmoschus esculentus* (L.) Moench]. *Journal of Vegetable. Crop Production 7*, 3–11

Pulatov, B., Hall, K., Anderson, M., & Jonsson, A. M. (2014). Effect of climate change on the potential spread of the Colorado potato beetle in Scandinavia: An ensemble approach. *Inter-Climate Research, 62*, 15-24

Reddy, G. V., Shi, P., Hui, C., Cheng, X., Ouyang, F., & Ge, F. (2015). The seesaw effect of winter temperature change on the recruitment of cotton bollworms *Herlicoverpa amigera* through mismatched phenology. *Ecology and Evolution, 5,* 5652-5661

Sharma, H. C., & Prabhaka, C. S. (2014). Impact of climate change on pest management and food security. Integrated pest Management (pp. 23-36). Academic Press, Elsevier, London, UK.

Stats SA (2011). Census 2011: Provincial profile: Limpopo/ Statistics South Africa. http://www.Stats Sa.gov.za/publications/report-03-01-78/report-03-01-782011

Tatlidil, F.F., Boz, I., & Tatlidil, H. (2009). Farmers' perception of sustainable agriculture and its determinants: a case study in Kahramanmaras Province of Turkey. *Environment Development and Sustainability, 11*, 1091-1106

Trionnaire, G. L., Wucher, V. & Tagu, D. (2013). Genome expression control during photoperiodic response of aphids. *Entomology, 38*, 117-125

Tshiala, M.F., Botai, F.O., & Olwoch, J.M. (2012). Leafminer agromyzed pest distribution over Limpopo Province under changing climate. *African Journal of Agricultural Research, 7,* 6515-6522

Ubisi, N.R., Mafongoya, P.L., Kolanisi, U., & Jiri, O. (2017). Smallholder farmer's perceived effects of climate change on crop production and household livelihoods in rural Limpopo Province, South Africa. *Change Adaptation Socioecology Systems, 3,* 27-38

VanDyck, H., Bonte, D., Puls, R., Gotthard, K., & Maes, D. (2014). The lost generation hypothesis: Could climate change drive ectotherms into a developmental trap*? OIKOS Synthesizing Ecology, 124,* 54-61

Vanhanen, H., Veteli, T.O., Paivinen, S., Kellomaki, S., & Niemela, P. (2007). Climate change and range shifts in two insect defoliators: gypsy moth and nun moth – a model study. *Silva Fennica, 41,* 4 article id 469

Visser, B., Willet, D.S., Harvey, J.A., & Alboin, H.T. (2017). Concurrence in the ability for lipid synthesis between life stages and insects. *The Royal Society, 4,* 160815

Ziska, L. H., & Mcconnell, L. L. (2016). Climate change, carbon dioxide and pest biology: Monitor, mitigate, manage. *Journal of Agricultural and Food Chemistry, 64,* 6-12

CHAPTER 4: EMERGING AND NEW PESTS OF VEGETABLE PRODUCTION UNDER CLIMATE CHANGE

Abstract

Vegetables are important in alleviating malnutrition in humans. As such, the demand for vegetables in developing countries is increasing. Vegetable production is constrained by pests that limit yield and this result in nutritional insecurity. Climate change and globalization are the main drivers of new and emerging pests in South Africa. This study was conducted in four municipalities (Makhado, Mutale, Thulamela and Musina) of Vhembe District in Limpopo Province. Qualitative and quantitative participatory methods were used for data collection. Results show that *Bagrada hilaris* (bagrada bug) and *Acanthoplus discoidalis* (armoured bush cricket) were emerging pests in Limpopo Province. New pests found were *Tuta absoluta* (South American tomato pinworm) and *Spodoptera frugiperda* (fall armyworm). *Tuta absoluta* was detected for the first time in Limpopo Province in 2016 and *Spodoptera frugiperda* was detected for the first time in the early summer months of 2017. *Tuta absoluta* was only reported in Musina municipality (79%). Fall armyworm was significantly higher in Makhado irrigated municipality (72%) than all municipalities and their landuse ($P < 0.05$). The lowest percentage of fall armyworm was reported in Musina municipality (8.33%). With respect to bagrada bug prevalence, Thulamela dryland system (73%) was significanthly different from Mutale irrigated system (28%) ($P < 0.05$). With respect to armoured bush cricket prevalence, Musina municipality was significantly different from the rest of the municipalities ($P < 0.05$). Mutale irrigated system (9.52%) had the lowest percentage of armoured cricket prevalence. Results indicated that these pests are more prevalent in summer and winter seasons. There is limited knowledge on the spread of these pests Limpopo Province. It can be concluded that due to poor phytosanitary measures and climate change, more new pests will continue to spread in Limpopo Province, South Africa. Increased temperatures and warmer winters could be responsible for emerging and new insect pests in Limpopo Province. There is need to train farmers to identify new insect pests. Studies on the biology of emerging and new insect pests is needed. There is need for production of pest's risk maps of pest distribution in order to increase preparedness of government and farmers in controlling these pests.

Key words*:* *Bagrada hilaris* (Bagrada bug); *Spodoptera frugiperda*, (fall armyworm) *Tuta absoluta*, (South American tomato pin worm), *Acanthoplus discoidalis* (armoured cricket); increased temperatures, warm winters

4.1. Introduction

Vegetable consumption is the first important step to overcome human malnutrition, especially to those who are more vulnerable to lack of nutrients (Yang and Keding, 2009). There is need to increase vegetables for human beings to obtain essential micronutrients through their diets (Ojiewo et al., 2015). The demand for vegetable is increasing especially in developing countries. Farmers with ease access to markets are in good position to obtain income through selling their vegetables (Dinham, 2003).

Vegetable production is most limited by pests. Amongst the known pests, insects account for 18% loss of crop production (Oerke, 2006). Oliveira et al (2014) reported that insect pest damage can result to 7.7% loss of production, which is equivalent to a loss of ± 25 million tons of food, thus resulting to food insecurity. Crop losses from insect pests are severe in subtropical and tropical areas due to high temperatures. This presence of pests has attracted high pesticide use by farmers due to increased pest outbreaks (Dinham, 2003).

Climatic changes such as high temperatures, extreme weather events, elevated carbon dioxide are expected to increase insect pest pressure through: migration of pests and invasion of pests to new areas, increase in insect population through shortened life cycles and increase of geographical range of insect (Reddy, 2013; Bale, 2002). The global temperature is expected to rise by 3.4 ^{o}C by the end of 21st century (Barzman et al., 2015). Limpopo Province is expected to have high prevalence of insect pests because of high temperatures (Moodley et al., 2014). Ectothermic insect pests are most likely expected in Limpopo Province because they are highly influenced by high temperatures (Bale, 2002).

Climatic changes can highly influence the survival of alien species in new regions. Global warming can influence alien species to adapt, reproduce and expand into regions where they did not survive in previous years. Most alien species survive in regions with climatic conditions that are similar to those of their native region (Walther et al., 2009). The presence of alien species in a new region does not automatically mean that the pest will establish successfully in the region. Only conducive factors such as climate and host can influence the success of pest establishment (Sax and Brown, 2000). Pests that reproduce asexually may establish successfully if climatic conditions and host are conducive (Sax and Brown, 2000). Adaptation of problematic insect pests to climatic conditions may be more problematic in their management (Macfadyen et al., 2016). Pests such as red spider mite can damage the whole field from the first day of its introduction if not detected early (Azandeme-Hounmalon et al., 2015).

The introduction of problematic alien pests usually results in management challenges. When farmers notice the first appearance of a new pest, the first management method they use is chemical control. However, farmers are not fully aware about which chemicals they need to use to control problematic alien species (Rai et al., 2014). Most of the chemicals that farmers apply on alien pests are not effective. This is because the chemicals used are not meant for new pests since the pest has not been native to the region (Azandeme-Hounmalon et al., 2015). Farmers also have a challenge in identifying and knowing the behaviour of alien pests because they are not familiar with the pests. Pests such as fruit flies are difficult to control if not well detected and studied because they pupate in the soil. Effective management of this pest can only be achieved if the soil is well treated with pesticides (Rai et al., 2014). Some alien pests are difficult to control because they have a wide range of hosts. Some alien pests find weeds as conducive habitat. For example, the American Serpentine leaf miner (*Liriomyza trifolii* Burgess) can reside on weed plants. This pest is regarded as an internal feeder, which makes it very difficult to be controlled by insecticides (Rai et al., 2014).

Some farmers use pheromone traps to monitor new pests entering the country (Baniameri and Cheraghian, 2012). Pheromone traps with light have been used to detect entry of *Tuta absoluta* in Iran (Baniameri and Cheraghian, 2012). *Tuta absoluta* is not easy to control since it appears similar to *Phthorimae opercuella* with the same behavioural characteristics. Smallholder farmers are expected to be more vulnerable because majority of them have no sufficient resources to manage alien insect pests (Visser et al., 2017).

Globalization and trade are increasing the rate at which insect pests are spreading to new countries (Hulme et al., 2008). *Spodoptera frugiperda* commonly known as fall armyworm is one of the major insect pests that has been spreading through people’s movement and trade to other countries (Cock et al., 2017). This pest has recently become the current alien species in west and central Africa (Goergen et al., 2016) and other African countries such as Nigeria, Togo and Ghana (Cock et al., 2017). *Spodoptera frugiperda* is a polyphagous insect that feeds on leaves, stems and fruits of more than 100 crop species (Pogue, 2002). This pest is commonly feeds on cereal crops such as maize, rice, and sorghum. However, it can also feed on crops such as cabbages, beet, onion, tomatoes, potatoes, cotton, millet, soybean and peanuts (CABI, 2016; Pogue, 2002).

Tuta absoluta, commonly known as the South American tomato pinworm is also one of the major tomato native pest introduced through trade and globalization. This pest was reported for the first time in the sub-Saharan Africa in 2012 (Pfeiffer et al., 2013). It was reported for the first time in countries such as Senegal, Niger, Ethopia and Sudan in 2012 (Pfeiffer et al., 2013; Brevault et al., 2014). This pest also feeds on pepper (*Capsicum annum* L.), tobacco (*Nicotiana tabacum* L.), potato (*Solanum tuberosum* L.), black nightshade (*Solanum nigrum*) and other Solanaceae species (Ferracini et al., 2012). The objective of this study was to determine new and emerging pests of vegetables in Limpopo Province, South Africa.

4.2. Materials and methods

4.2.1. Description of study site

The study was conducted in South Africa, Limpopo Province in four municipalities of Vhembe District (22.7696º S, 29.9741º E). Vhembe District constitutes of four municipalities, which are: Mutale (22.5108º S, 30.8039º E), Thulamela (22.8922º S, 30.6200º E), Makhado (23.0462º S, 29.9047º E) and Musina (22.3953º S, 29.6963º E). Within the district is Musina municipality, which shares a border with Zimbabwe through the Beit bridge gate (Brournels, 2014). The population in this district is about 68.359 and the majority of this population number are black people (Stats, 2011). Vhembe District is characterized by semi-arid climates and it experiences dry spells with high temperatures throughout the year (Mpandeli, 2006). In some areas such as Musina municipality, rainfall ranges around 372 mm in summer seasons (Mpandeli, 2006) whereas rainfall is about 137 mm in Mutale municipality (Brournels, 2014). This district was chosen because it is known for experiences in high temperatures and erratic rainfall. This means that farmers in these areas are more vulnerable to climatic changes. Vegetables such as tomatoes, cabbages, black nightshade and mustard spinach are the standard vegetables grown in this district. These vegetables are mostly grown in areas ranging from 1 hectare and above. Maize, and sweet potato are the main standard field crops grown in Vhembe District. The common methods used for irrigation are drip irrigation and furrow irrigation for those who have access to water. In most of these municipalities, vegetables are rotated with field crops occasionally.

4.2.2. Study approach

Sampling concentrated on smallholder farmers found in rural areas and in peri-urban areas. Hundred and sixty-three farmers were selected randomly from a list of household farmers provided by extension officers. Quantitative data was collected using questionnaires. Qualitative data was collected through focus group discussions and key informants. Three focus groups were conducted in each municipality. This consisted of seven women alone, seven men alone and a combined group of seven men and seven women. Seven women and seven men were randomly selected from a list of farmers who did not participate in the questionnaire study. Key informants selected in each municipality were extension officers and old age farmers familiar with the municipality. A checklist was used to collect qualitative data from key informants and focus group.

4.2.3. Data analysis

The data was encoded in IBM Statistical Package for Social Sciences (SPSS) 23. Chi-square was used to compare the differences between different variables. Means and significant differences between means were declared at $P \leq 0.05$.

4.3. Results

4.3.1. Indicators of climate change

The majority of farmers both in dryland and irrigated systems were aware of climate change and were able to identify the indicators of climate change. Within dryland systems, Makhado municipality (57.1%) was significantly different from Thulamela municipality (44.4%), but was not significantly different from Mutale municipality (50%) with respect to late rainfall as indicator of climate change. Thulamela municipality (48.1%) was significantly different from Mutale municipality (28.6) and Makhado municipality (14.3%) with respect to increased drought frequency ($P < 0.05$) (Figure 4.1). With respect to long dry spells, Thulamela municipality (59.3%) was significantly different from Mutale municipality (7.1%) and Makhado municipality (42.9%). With respect to shorter rainy season, Makhado municipality (21.4%) and Mutale municipality (17.9%) were significantly different from Thulamela municipality (11.1%) but not significantly different from each other. Mutale municipality (10.7%) was significantly lower from Thulamela municipality (18.5%) and Makhado municipality (25%) in terms of shorter cold season. With respect to increased flood frequency, Mutale municipality (3.6%) and Thulamela municipality (3.7%) were significantly different from Makhado municipality (14.3%) but were not significantly different from each other.

In irrigated systems, with respect to late rainfall, Thulamela municipality (66.7%) was significantly different from Mutale municipality (32.1%) and Musina municipality (42.9%) but was not significantly different from Makhado municipality (58.6%) (Figure 4.1). In terms of erratic rainfall, Mutale, Makhado and Musina municipalities exhibited similar responses but were significantly different from Thulamela municipality. Musina (32.1%) and Thulamela (29.6%) municipalities were similar to each other in terms of shorter rainy seasons, but were significantly different from Makhado municipality (10.3%) and Mutale municipality (3.6% which were not significantly different from each other. With respect to increased flood frequency, Musina municipality was significantly lower than the rest of the municipalities ($P < 0.05$).

Within municipalities and landuse, increased drought frequency was significantly higher in Thulamela irrigated system (55.6%) as compared to the rest of municipalities and their landuse. The lowest percentage was found in Makhado dryland system (14.3%). In Makhado dryland system, increased flood frequency was significantly higher from the rest of the factors indicating climate change ($P < 0.05$). In Musina municipality (3.6%), increased flood frequency was significantly lower from the rest of the climatic indicators ($P < 0.05$).

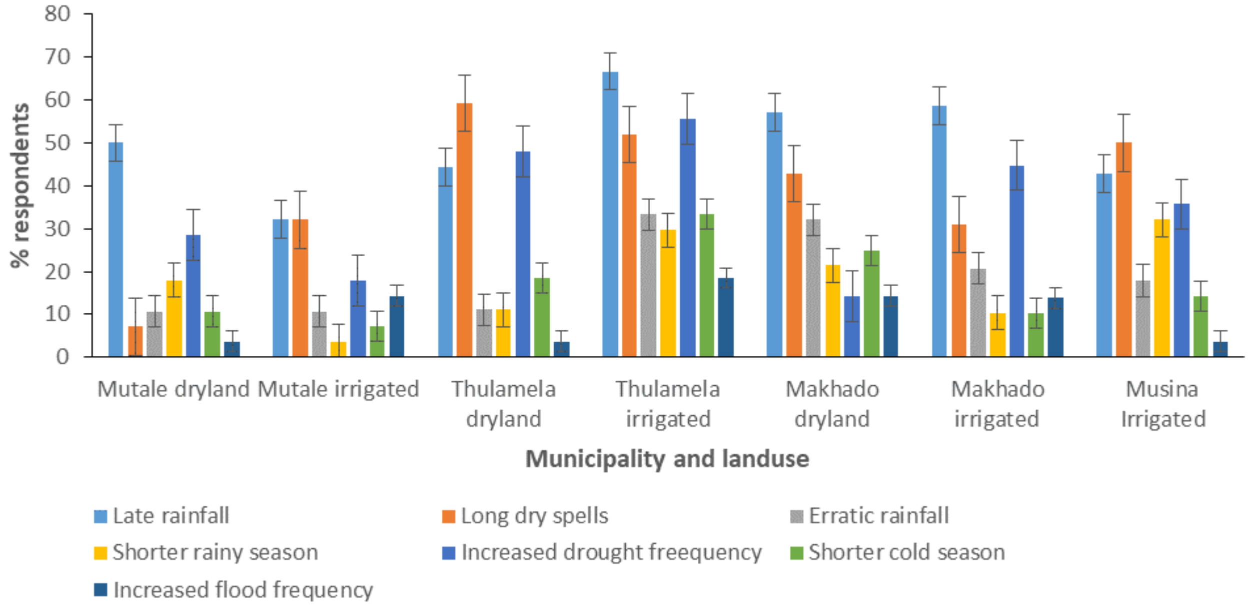

Figure 4.1: Indicators of climate change
Bars represent standard error (SE) of the mean

4.3.2. New and emerging insect Pests in Vhembe District

In dryland systems, with respect to bagrada bug, Thulamela municipality (73%) was significantly different from Mutale municipality (56%) and Makhado municipality (29%) (Figure 4.2). The damage done by bagrada bug on mustard spinach is shown in Figure 4.3.b. Makhado municipality (50%) was significantly different from Thulamela municipality (19%) with respect to fall armyworm prevalence. With respect to armoured bush cricket, Mutale municipality (36%) was not significantly different from Makhado municipality (29%) ($P > 0.05$). Amoured bush cricket was not reported in Thulamela municipality. *Tuta absoluta* was not recorded in all dryland systems.

In irrigated systems, with respect to bagrada bug occurrence, Makhado municipality (56%) was significantly different from Thulamela municipality (33%) and Mutale municipality (28%) which did not show any significant difference from each other ($P < 0.05$) (Figure 4.2). With respect to fall armyworm, Makhado municipality (72%) was significantly different from

Thulamela municipality (50%) and Musina municipality (8.33%). The damage done by fall armyworm is shown in figure 4.3.d. Musina municipality is the only one, which reported the presence of *Tuta absoluta*. The damage done by Tuta ansoulta is shown in figure 4.3.f. With respect to armoured bush cricket Musina municipality (50%) was significantly different from Thulamela municipality (29%) and Makhado municipality (24%) which were not significantly different from each other. The damage done by amoured cricket on maize is shown in figure 4.3.g. In both irrigated and dryland systems, these insect pests were also mentioned to be problematic during focus group discussions.

Within municipalities, fall armyworm was significantly different from the rest of the insect pests in both dryland and irrigated systems of Makhado municipality. In Thulamela dryland system, bagrada bug (73%) was significantly different from fall armyworm (19%). In Musina municipality, fall armyworm was significantly lower than the rest of the insect pests.

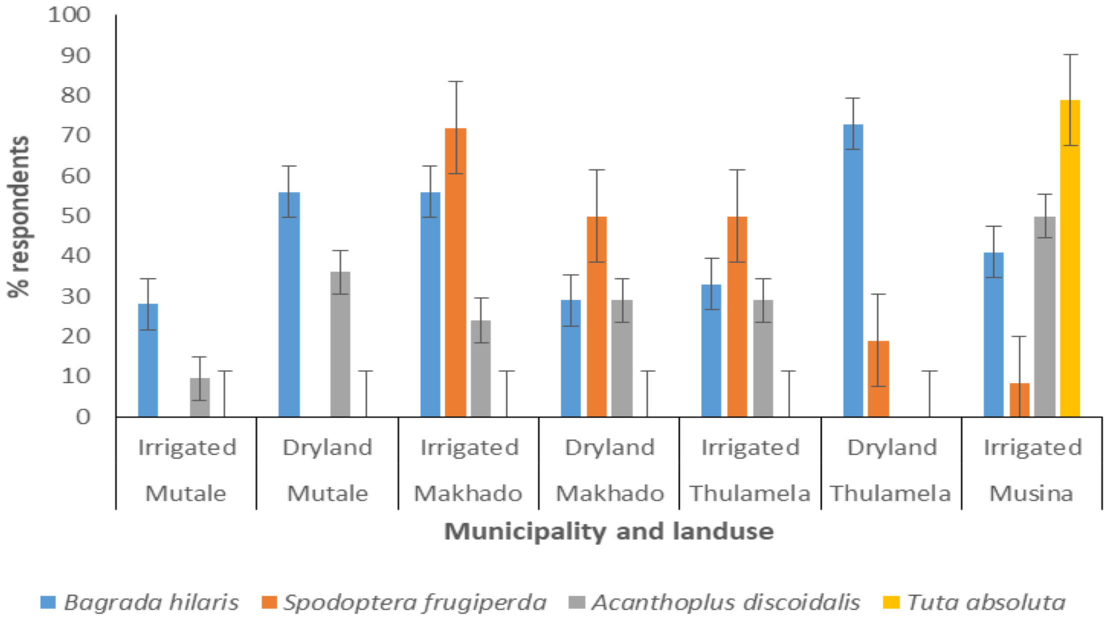

Figure 4.2: Occurrence of new and emerging insect pests
Bars represent standard error (SE) of the mean

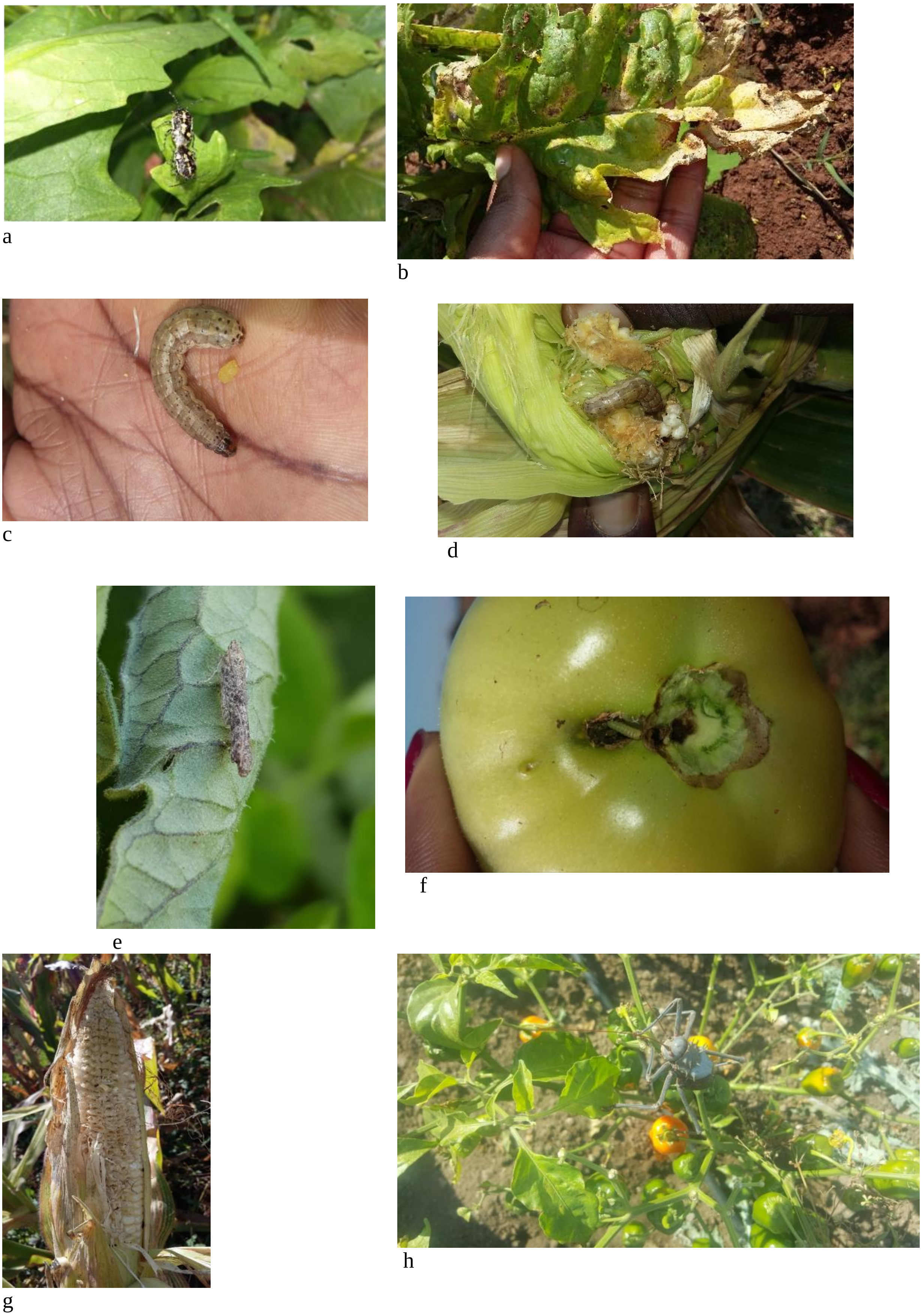

Figure 4.3: Emerging and new pests found in Vhembe District *a. bagrada bug on mustard spinach, b. damage on mustard spinach caused by bagrada bug, c. fall armyworm found in Makhado municipality, d. damage on maize crop*

caused by fall armyworm, *e.* ***Tuta absoluta on tomato leaf,*** *f.* ***damage on tomato fruit caused by tuta absoluta,*** *g.* ***damage onmaize caused by armoured bush cricket,*** *h.* ***armoured bush cricket on pepper crop.***

4.3.3. Factors influencing insect pests' incidence

Across all dryland systems, in terms of poor insect management, Makhado municipality (35.7%) showed significant difference from Mutale municipality (21.4%) and Thulamela municipality (14.8%) ($P < 0.05$) (Figure 4.4). There was no significant difference with respect to low rainfall in Mutale municipality (25%) and Makhado municipality (25%). Thulamela municipality (51.9%) was significantly different from Makhado (17.9%) and Mutale (3.6%) with respect to warmer winters influencing pest incidence.

In irrigated systems, Thulamela municipality (70.4%) was significantly different from Musina municipality (50%), Makhado municipality (20.7%) and Mutale municipality (25%) with respect to increased dry spells (Figure 4.4). With respect to low rainfall, Musina municipality was significantly different from the rest of the municipalities ($P < 0.05$). With respect to warmer winters, Thulamela municipality was significantly different from the rest of the municipalities ($P < 0.05$). The lowest percentage was found in Mutale municipality (7.1%).

Within municipalities, in Thulamela irrigated system, increased dry spells was significantly different from the rest of the factors. In Musina municipality, increased dry spells (50%) and low rainfall (42.9%) did not show any significant difference amongst each other but were significantly different from the rest of the factors. In Makhado irrigated system, shortened winter was significantly different from the rest of the factors.

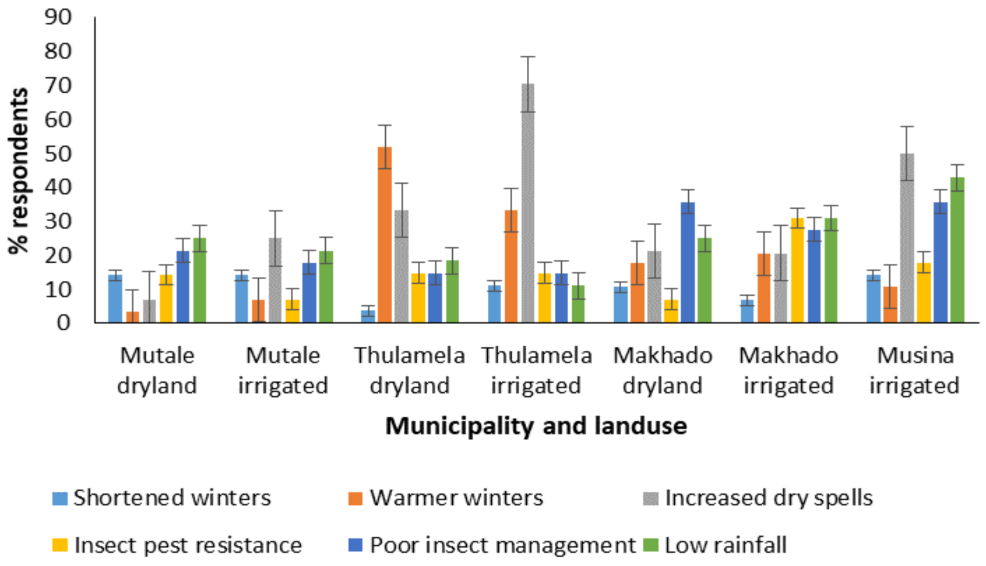

Figure 4.4: Factors leading to increased pest incidence
Bars represent standard error (SE) of the mean

4.3.4. Pest prevalence across seasons

In irrigated systems, Thulamela municipality was significantly different from the rest of the municipalities in terms of pest prevalence in summer season ($P < 0.05$). The highest frequency of respondents was found in Thulamela municipality (77.8%) and the lowest was found in Mutale municipality (32.1%) (Table 4.1). Mutale municipality (39.3%) and Thulamela municipality (3.7%) was significantly different from each other and from the rest of the municipalities in terms of pest prevalence in winter season. Makhado municipality (13.8%) and Musina municipality (14.3%) did not show significant difference amongst each other with respect to pest prevalence in winter season.

In all dryland systems, all municipalities (Mutale, Thulamela and Makhado) agreed that insect pests are more prevalent in summer followed by winter season, and were not significantly different from each other (Table 4.1). The highest respondent frequency on pest prevalence in summer season was found in Mutale municipality (64.3%) and the lowest was found in Makhado municipality (53.6%). For pest prevalence in winter season, the highest was recorded in Makhado municipality (21.4%) and the lowest respondent frequency was recorded in Mutale municipality (10.7%).

In both dryland and irrigated systems of Thulamela municipality, summer, winter and autumn were all significant amongst each other ($P < 0.05$). In the irrigated system of Makhado, winter season (13.8%) and all year round (24.1%) were not significantly different from each other but were significantly different from summer season (48.3%). In Musina municipality, autumn season (3.6%) and all year round (7.1%) were not significantly different from each other but showed significant difference from summer (60.7%) and winter (14.3%) seasons.

Table 4.1: Season of the year when pest are most prevalent

	Mutale Municipality		**Thulamela Municipality**		**Makhado Municipality**		**Musina Municipality**
Season	**dryland**	**irrigated**	**dryland**	**irrigated**	**dryland**	**irrigated**	**irrigated**
Summer	64.3b	32.1c	59.3b	77.8a	53.6b	48.3b	60.7b
Autumn	3.6e	3.6e	7.4e	0	3.6e	0	3.6e
Winter	10.7d	39.3c	18.5d	3.7e	21.4d	13.8d	14.3d
Spring	0	3.6e	0	0	0	0	0
All year round	3.6e	7.1e	0	3.7e	7.1e	24.1d	7.1e
STDEV	27.03	17.19	24.81	34.02	21.94	20.11	24.92

Means followed by the same letter are statistically similar at $P \leq 0.05$

4.4. Discussion

Farmers across all systems in all municipalities indicated long dry spells, erratic rainfall and warmer winters as indicators of climate change. This means that farmers were aware of climatic changes in these areas. Mendelsohn (2008) has indicated that increased temperatures are signs of climate change, and are still expected to rise in the next century (Barzman et al., 2015). Gbetibouo et al (2010) reported that Limpopo Province is one of the provinces vulnerable to climate change due to high temperatures. South Africa has been experiencing high temperatures for many years (Elum et al., 2016). This gives a clear indication why farmers are experiencing high temperatures even in winter seasons. Dryland farmers are highly depended on rainfall due limited availability of water; therefore, these farmers are expected to be highly vulnerable to climatic changes such as late rainfall, increased drought efficiency and high temperatures compared to irrigation farmers. Vulnerabilty to climate change in Limpopo Province will most likely disrupt the livelihoods and wellbeing of smallholder farmers in many regions (Gbetibouo et al., 2010).

Although farmers are aware of problematic insect pests in their land use (as discussed in chapter 3), they are also aware of new and emerging insect pests that are problematic to their vegetables and field crops. Bagrada bug has been mentioned as a major pest of mustard spinach. According to focus group discussions, farmers mentioned that this pest was present before. However, this pest has been more problematic recently, causing severe damage on mustard spinach crops. Bagrada bug can be effectively triggered by high temperatures. Its reproduction rate and mobility rate are highly influenced by high temperatures (Huang et al., 2013). This supports the increasing prevalence of bagrada bug in Limpopo Province due to increasing temperatures. Farmers indicated that armoured bush cricket was a problematic insect pest of maize crops, feeding on maize kernels. The reason why it was found in all municipalities is that all municipalities grow maize during summer season. This pest was more problematic in dryland systems. Farmers in Mutale also mentioned that this insect pest also feed on sorghum, millet and pepper. Farmers indicated that they use cultural methods to manage amoured bush cricket due to lack of chemicals. They handpick them and store in bottles, then burn them. However, famers mentioned that this method can be very time consuming.

Tuta absoluta is a serious pest in tomato fruits and it is native to South America (Desneux and Luna, 2011). One of the major crops grown in Musina municipality are tomatoes. This gives the reason why this pest was found in abundance and resulted in severe damage in Musina municipality. *Tuta absoluta* was mentioned to be more problematic in Musina municipality than the rest of the municipalites. Farmers mentioned that the pest was first detected in Limpopo Province in 2016. This is supported by Visser et al (2017) who reported first detection of *Tuta absoluta* in South Africa during October 2016. *Tuta absoluta* has also been reported for the first time in other sub-Saharan countries including Kenya, Tanzania and Uganda (Pfeiffer et al., 2013). This pest was suspected to have arrived in South Africa through trade, poor border phytosanitary measures, and inadequate quarantine methods (Desneux and Luna, 2011). Farmers mentioned that during its arrival, they confused *Tuta absoluta* with other leaf miners that have been prevalent in Musina municipality. *Tuta absoluta* can be easily confused with *P. operculella* due to their similar appearance and behaviour (Visser et al., 2017). This pest has been spreading and resulting in severe damage on tomato fruits. This might have been influenced by increased temperatures and high production of tomatoes throughout the whole year in Musina municipality. Limpopo Province produces 66% tons of tomato annually (NDA, 2009). High temperature can highly influence the mobility and distribution of insect pests, and therefore resulting in severe damage caused by the pest (Ziska and McConnell, 2016). Given the fact that Limpopo Province is a high temperature region, *Tuta absoluta* is expected to result in huge damage on tomatoes due to its high mobility as influenced by high temperatures.

Farmers indicated that fall armyworm was first detected in early 2017 during maize growing season. Farmers mentioned that this pest was found feeding on maize, causing severe damage to maize crops. Farmers indicated that this pest was feeding on the apical meristem of young maize plants and also maize kernels. It was also confused with the common stalk borer that farmers already knew. Fall armyworm is also suspected to have arrived in South Africa through trade and movement of people from other countries (Cock et al., 2017). Fall armyworm has been reported lately in other countries in Africa such as Ghana and other west African countries and it was predicted to spread continuously in other African countries (Goergen et al, 2016). So far, farmers have indicated that fall armyworm feeds on maize and grass weeds. This pest was more prevalent in these municipalities because maize was one of the major crops widely grown as a staple crop. Therefore, its presence is most likely to increase due to landuse factor. The damage caused by fall armyworm can be severe under high temperatures (Valdez-Tores, et al., 2012).

According to the results, low rainfall, increased dry spell, and warmer winters were the key factors resulting in increased pest prevalence in Limpopo Province. During farmer's survey and focus group discussions, farmers indicated that temperatures have increased tremendously followed by high rates of erratic rainfall. Increased temperatures can influence the rate of insect population, increase in number of generations and mobility of insect pests (Meisner et al., 2014). Farmers have indicated that warmer winters had an influence in insect pests' prevalence. According to them, these pests were normally expected in summer season. However, high temperatures in winters have influenced more presence of these pests in their regions. Warmer winters can result in mortality reductions of insect pests, thus leading to high rates of populations and increased damage to crops (Harrington et al., 2001). The other reasons why some of these insect pests were prevalent in winter season is because of the crops grown throughout the seasons. The majority of farmers were found to be growing same crops all year round irrespective of whether the season is appropriate to grow certain crops or not. This influenced the presence and spread of insect pests even in winter season when temperatures were high. Farmers mentioned that bagrada bug was found in winter season on mustard spinach crop. Musolin et al (2009) reported that hemipteran pests can increase their survival rate in winter if temperatures are high, thus resulting in increased population and damage on crops. During warmer winters, bagrada bugs are commonly seen in mating pairs (Reed et al., 2013). This is why this pest was also seen in Limpopo Province during winter seasons.

Farmers mentioned that insect pests were more prevalent in summer and winter season as compared to spring and autumn. A study was done in Limpopo province and its results indicated that eastern parts of Limpopo Province including Musina and Polokwane experiences higher temperatures in summer season (Kruger and Shongwe, 2004). During the months of October to March, temperatures are higher and during December to January temperatures range around 25 ^{o}C and higher (Tshiala et al., 2011). Farmers mentioned that maximum temperatures have increased in winter seasons in Vhembe district. In the 1960 to 1990 decade, winter temperatures in Limpopo Province were about 18.18 ^{o}C. However, in 1991 to 2003, winter temperatures have increased to 18.48 ^{o}C (Kruger and Shongwe, 2004). This means that the average temperatures have been increasing in the past decades and are still expected to increase in the next decades. Average winter temperatures in Limpopo Province are around 20 ^{o}C. In July month, the highest temperatures range about 22 ^{o}C

(Tshiala et al., 2011). This explains why more insect pests were prevalent in summer and winter season than spring and autumn seasons.

4.5. Conclusion

The study aimed at understanding climate change indicators, new and emerging insect pests in Limpopo Province, and the prevalence of the insect pests in different seasons. This study indicated that low rainfall, long dry spells and warmer winters were the most common indicators of climate change and were clearly distinguished and understood by farmers. This study clearly indicated that bagrada bug and amoured bush cricket were emerging pests in Limpopo Province. These pests were reported as minor pests, but due to climatic changes, these pests have adapted to high temperatures and are now regarded as major pests. *Tuta absoluta* and *Spodoptera frugiperda* were regarded as new pests in the district. According to this study, this was the first detection of fall armyworm across the municipalities in Vhembe District. This pest has managed to adapt to climatic changes such as high temperatures of this region. It is expected that these pests will continue to adapt to these changes and will increase its mobility, population size, and will result to severe crop damage if not properly managed. According to the results, it can be concluded that Limpopo Province and other provinces will be more vulnerable to other new pests due to poor phytosanitary measures at country borders and airports. Therefore, there is need for early warning systems and risks maps of new and emerging insect pests for farmers to be aware and to prepare strategies in which the pests can be managed. More research is needed to study the biology of these new and emerging insect pests. There is also a need of production of risk maps on pest distribution in order to increase preparedness of government and farmers in controlling the spread of these pests.

References

Azandeme-Hounmalon G.Y., Torto B., Fiaboe K.K.M., Subramanian S., Kreiter S. & Martin T. (2016) Visual, vibratory, and olfactory cues affect interactions between the red spider mite Tetranychus evansi and its predator Phytoseiulus longipes . *Journal of Pest Science, 89,* 137–152

Bale, J.S. (2002). Insects and low temperatures: from molecular biology to distributions and abundance. *Philosophical Transactions: Biological Sciences 357,* 849-862

Baniameri, V., & Cheragian, A. (2012). The first report and control strategies of *Tuta absoluta* in Iran. *Bulletin OEPP/EPPO Bulletin, 42,* 322-324

Barzman, M., Lamichhane, J.R., Booij, K., Boonekamp, P., Desneux, N., Huber, L., Kudsk, P., langerell, S.R.H., Ratnadass, A., Ricci, P., Sarah, J., & Messean, A (2015). Research and priorities in the face of climate change and rapidly evolving pest. *Sustainable Agriculture Reviews, 17,* 1-27.

Brevault, T., Sylla, S., Diatte, M., Bernades, G., & Diarra, K. (2014). Tutal absoluta Meyrick (Lepidoptera: Gelechiidae): a new threat to tomato production in sub-Saharan Africa: short communications. *African Entomology, 22*, 441-444

Brournels, M. (2014). The local government handbook of South Africa 2014: a complete guide to municipalities in South Africa, 4th edistion. Yes! Media, Calermount, RSA, Pp. 2015

CABI (internet) http://www.plantwise.org/knowledeBank/Datasheet.aspx?dsid=29810

Cock, M.J.W., Beseh, P.K., Buddie, A.G., Cafa, G. & Crozier, J. (2017). Molecular methods to detect *Spodptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. *Scientific Reports, 7,* 4103

Desnuex, N., & Luna, M.G. (2011). The invasive South American tomato pinworm, Tuta absoluta, continues to spread in Afro-Eurasia and beyond: the threat to tomato world production. *Journal of Pest Science, 84,* 403-408

Dinham, B. (2003). Growing vegetables in developing countries for local urban populations and export markets: problems confronting small-scale producers. *Pest Management Science, 59,* 575-582

Elum, Z.A., Modise, D.M., and Marr, A. 2016. Farmer’s perception of climate change and responsive strategies in three selected provinces of South Africa. *Climate Risk management, 16,* 246-257

Ferracini, C., Ingegno, B.C, Navone, P., Ferrari, E., Mosti, M., Tavelta, L., & Alma, A. (2012). Adaptation of indigenous larval parasitoids to *Tuta absoluta* (Lepidoptera: Gelechiidae) in Italy. *Journal of Economic Entomology, 105,* 1311-1319

Gbetibouo, G.A., Ringler, C., & Hassen, R. (2010). Vulnerability of the South African farming sector to climate change and vulnerability: An indicator approach. *Natural Resource Forum 34,* 175-187

Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A., & Tamo, M. (2016). First report of outbreaks of the fall armyworm spodoptera fruigiperda (J E Smith) (Lepidoptera, noctuidae), a new alien invasive pest in west and central Africa. *PLOS ONE, 11* (10): e0165632

Harrington, R., Fleming, R. A., & Woiwod, I. P. (2001). Climate change impacts on insect management and conservation in temperate regions: Can they be predicted? *Agricultural and Forestry Entomology, 3,* 233-240

Huang, T.-I., Reed, D. A., Perring, T. M., & Palumbo, J. C. (2013). Diel activity and behaviour of Bagrada hilaris (Hemiptera; pentatomidae) on dessert cole crops. *Horticultural Entomology, 106,* 1726-1738.

Hulme, P. E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., Nentwig, W., Olenin, S., Panov, V., Pergl, J., Pysek, P., Roques, A., Sol, D., Solarz, W., & Vilà, M. (2008). Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *Journal of Applied Ecology, 45*, 403-414

Kruger, A.C., & Shongwe, S. (2004). Temperature trends in South Africa: 1960-2003. *International Journal of Climatology, 24*, 1929-1945

Macfadyen, S., Mcdonald, G., & Hill, M. P. (2016). From species distribution to climate change adaptation: knowledge gaps in managing invertebrate pests in broad-acre grain crops. *Agriculture, Ecosystems & Environment* (In Press)

Meisner, M. H., Harman, J. P., & Ives, A. R. (2014). Temperature effects on long-term population dynamics in a parasitoid-host system. *Ecological Monographs, 84*, 457-476

Mendelsohn, R. (2008). The impact of climate change on agriculture in developing countries. *Journal of Natural Resource Policy Research, 1*, 5-19.

Moodley, V., Ibaba, J.D., Naidoo, R., & Gubba, A. (2014). Full-genome analyses of a Potato Virus Y (PVY) isolate infecting pepper (*Capsicum annuum* L.) in the Republic of South Africa. *Virus Genes 49,* 466-476

Mpandeli, S.N. (2006). Coping with climate variability in Limpopo Province. Unpublished PhD thesis, University of Witwatersrand lessons from southern Africa. *South African Journal of Science, 105,* 34-49

Musolin, D. L., Tougou, D., & Fujisaki, K. (2009). Too hot to handle? Phenological and life history responses to simulated climate change of the southern green stink bug *Nezara viridula* (Heteroptera: pentatomidae). *Global Change Biology, 16*, 73-87.

NDA (2009). Directorate: Agricultural Statistics Section. Pretoria, South Africa.

Oerke, E.C. 2006. Crop losses to pests. *Journal of Agricultural Science, 144,* 31-43

Ojiewo, C., Keatinge, D. J. D. H., Hughes, J., Tenkouano, A., Nair, R., Varshney, R., Siambi, M., Monyo, E., Ganga-Rao, N.V.P.R., & Silim, S. (2015). The Role of Vegetables and Legumes in Assuring Food, Nutrition, and Income Security for Vulnerable Groups in Sub-Saharan Africa. *World Medical & Health Policy, 7,* 3

Oliveira, C.M., Auad, A.M., Mendes, S.M., Mendes, S.M., & Frizzas, M.R. (2014). Crop losses and the economic impact of insect pests on Brazilian agriculture. *Crop Protection, 56*, 50-54

Pfeiiffer D.G., Muniappan, R., Sall, D., Diatta, P., Diongue, A., & Dieng, E.O. (2013). First record of Tuta absoluta (Lepidoptera: Gelechiidae) in Senegal. *Fla Entomology, 96,* 661-662

Pogue, M. (2002). A world revision of the genus *Spodoptera guenée* (Lepidoptera: Noctuidae). *Memoirs of the American Entomological Society, 43*, 1–202.

Rai, A.B., Halder, J., & Kodandaram, H. (2014). Emerging insect problems in vegetable crops and their management in India: an appraisal. *Pest Management in Horticultural Ecosystems, 20*, 113-122

Reed, D. A., Palumbo, J. C., Perring, T. M., & May, C. (2013). *Bagrada hilaris* (Hemiptera: Pentatomidae) an invasive stink bug attacking Cole crops in the south-western United States. *Journal of Integrated Management, 4,* 1-7.

Reddy, P. P. (2013). Impact of climate change on insect pests, pathogens and nematodes. *Pest Management in Horticultural Ecosystems, 19,* 225-233.

Sax, D.F., & Brown, J.H. (2000). The paradox of invasion. *Global Ecology, 9,* 363-371

Stats SA (2011). Census 2011: Provincial profile: Limpopo/ Statistics South Africa. http://www.Stats Sa.gov.za/publications/report-03-01-78/report-03-01-782011

Tshiala, M.F., Botai, F.O., & Olwoch, J.M. (2012). Leafminer agromyzed pest distribution over Limpopo Province under changing climate. *African Journal of Agricultural Research, 7,* 6515-6522

Valdez-Torez, J.B., Soto- Landeros, F., Osuna-Enciso, T., & Baez-Sanudo, M.A. (2012). Phenological prediction models for white corn (*zea mays* L) and fall armyworm (*Spodoptera fruigiperda* J.E. Smith). *Agrociencia, 46,* 399-410

Visser, B., Willet, D.S., Harvey, J.A., & Alboin, H.T. (2017). Concurrence in the ability for lipid synthesis between life stages and insects. *The Royal Society, 4,* 160815

Walther, G., Roques, A., Hulme, P.E., Sykes, M.T., Pysek, P., Kuhn, I., & Zobel, M. (2009). Alien species in warmer world: risks and opportunities. *Trends in Ecology and Evolution, 24,* 686-693

Yang, R. Y., & Keding, G. B. (2009). Nutritional contributions of important African indigenous vegetables. In C. M. Shackleton, C. M., Pasquini, M. W., & A. W. Drescher (Eds.), *African Indigenous Vegetables in Urban Agriculture* (Ch. 4, pp. 10-35). Earthscan, London.

Ziska, L.H., & McConnel, L.L. (2016). Climate change, carbon dioxide and pest bilogy: Monitor, mitigate, manage. *Journal of Agricultural and food Chemistry, 64,* 6-12.

CHAPTER 5: FARMER PEST CONTROL MEASURES IN VEGETABLE PRODUCTION

Abstract

Pests and diseases are the major constraints in vegetable production for both commercial and smallholder farmers in Limpopo Province. Insect pests alone account for 18% of crop yield loss. Farmers in Limpopo Province were assessed in terms of control measures they used for controlling insect pests on vegetable and field crops. This study was conducted in Limpopo Province, in four municipalities of Vhembe District: Mutale, Makhado, Musina and Thulamela using quantitative and qualitative data collection methods. Famers in all municipalities grew maize as their staple crop. Tomatoes were widely grown crops in Musina and Makhado municipality. About (82%) of irrigated systems of Mutale and Makhado municipalities, farmers were significantly different from the rest of municipalities and their landuse with respect to use of chemical control to manage insect pests ($P < 0.05$). Makhado dryland system (60.7%) was significantly higher than the rest of the municipalities with respect to ineffectiveness of chemical control ($P < 0.05$). The majority of farmers indicated that they only applied chemicals once a week. This might result in high levels of pesticide residue build up on vegetables and can be detrimental to human health. It may also result in high levels of pesticide resistance and environmental contamination. There is need for further training on other methods of pest management in Vhembe District. Future research should asses the effect of pesticide residues on human health and farmer training on these issues.

Keywords: pesticide use, application frequency, chemical rotation, natural enemies

5.1. Introduction

Vegetable consumption provides essential micronutrients to human diet. Vegetable production is constrained by pests and diseases (Oerke, 2006). Most vegetables grown by farmers attract high rates of pesticide application due to high insect pest prevalence (Dinhamin, 2003). Most farmers in developing countries have high reliance on pesticides to manage insect pests and diseases. The demand for vegetables is increasing in developing countries, and its export rate to neighbouring countries has increased (DAFF, 2015). Therefore, this demand has attracted high rates of pesticide reliance by farmers.

Pesticides have been introduced in the past decades to manage problematic pest in agricultural production (Aktar et al., 2009). Farmers use pesticides in order to reduce crop yield loss resulting from pests and disease damage. However, due to increased pests' outbreaks and high adaptive rates of pests to new environments, the use of pesticides by farmers have increased. This has led to high rates of pesticide resistance (Carvalho, 2006). Chemical control has become the most common method for farmers to manage pests than the other methods (Fishel, 2007). Pesticide use by farmers has been reported to be higher in urban and peri-urban areas in developing countries. Zambia is one of the developing countries that has about 61% farmers from urban areas who are relying on chemical control, whereas 78% of farmers relying on chemical control come from peri-urban areas (Drescher, 2001). Research indicates that most of the pesticides used by farmers are insecticides and fungicides (Ahouangniou et al., 2012). This indicates that farmers are facing more problems induced by insect pests and crop diseases. In Southern Benin, 100% of farmers were reported to be highly dependent on insecticides to manage insect pests (Ahouangniou et al., 2012). While in Tanzania, 59% of farmers depended on insecticides and only 29% used fungicides to manage diseases (Ngowi et al., 2007).

Despite the development of insect resistance build up, pesticides have other undesirable effects if proper precautions are not well followed. Most farmers do not follow safety measures when applying chemicals (Hashemi et al., 2012). About 60% of farmers in Iran were not following the basic pesticide measures and many of them were not using any protective measures during pesticide application (Hashemi et al., 2012). Many farmers, especially those in rural areas have not yet received good training in pesticide use. Some farmers feel free to eat food and apply chemicals at the same time, and some even eat their food without washing hands after application. All these bad habits are due to lack of training on pesticide application (Dinham, 2003).

Most studies conducted in Africa indicated that there is high poor pesticide practice by farmers (Sibanda et al., 2003; Ashburner and Friedrich, 2001; Matthews et al., 2003; Hashemi et al., 2012). Some of the bad practices are that farmers are mixing chemicals with bare hands, tasting the concentration of chemicals using their tongues, application of chemicals on crops with brushes and increased frequency in application (Addo et al., 2002; Dinham, 2003). Such practices are harmful to human health. There are few studies that have been conducted in Africa on the consequences of poor pesticide application on human health

(Williamson et al., 2008; Ntow et al., 2006). Most of the consequences result from exposure of pesticides during application (de Bon et al., 2014). About 88% of pesticide exposure occurs in informal settlements and 73% of children in South Africa suffer from atopic dermatitis due to pesticide exposure (Tolosana et al., 2009). Majority of cotton farmers in Ghana have been reported sick after pesticide application due to pesticide exposure during application (Williamson et al., 2008).

Poor pesticide use can be hazardous to livestock, wildlife, soil organisms, water and can contaminate soils (Pretty and Waibel, 2005). Pesticides such as carbofuran, chloropyriphos ethyl and endosulfan are found to be normally used in gardens especially in developing countries. These pesticides have been reported to be harmful to the environment if not used correctly and if proper measures are not followed (Ahouangninou et al., 2012).

Most developing countries have legislation of chemicals that are restricted to be used for pest control (Ecobichon, 2001). About 3.2% of pesticides used by farmers in Iran are regarded as dangerous and 11.8% are extremely poisonous chemicals (Yousefi, 2008). Many farmers have increased the frequency of pesticide application with the aim of effectively controlling insect pests on vegetables. There are very few studies conducted on the impact of pesticide application frequency, especially in developing countries. Countries such as South Africa, Uruguay, Brazil, Malaysia and Argentina have increased pesticide application per hectare on crops (Schreinemachers and Tipraqsa, 2012). More than 50% of farmers have increased frequency in pesticide application as well as the dosage due to increased pest outbreaks on their crops (Xu et al., 2008). Most farmers use calendar spraying method, whereby they apply pesticides at certain set interval days, for example every 14 days' interval. However, with this type of pesticide application, farmers tend to apply chemicals even when there is no sign of pests on their crops (Dinham, 2003). Frequency in pesticide application can also differ according to climatic conditions and different seasons. During rainy conditions, farmers increase their frequency in pesticide application due to quick wash off of pesticides after application (Mazlan and Mumford, 2005). Farmers in Jessore, Bangladesh have been found to be spraying pesticides 3 times a week during summer season (Dinham, 2003). This can be influenced by high population of pests due to high temperatures, especially for ectothermic insects. Such type of application can increase the level of resistance build up by insect pests and this will have implications when controlling pests.

It is very common for farmers to mix different chemicals for effective control. Although they mix different chemicals, they are still found to be spraying these pesticides in high dosages even when there is no sign of insect pests in their crops (Dinham, 2003). This kind of pesticide application has detrimental effects on human health and the environment. Majority of farmers in Kuwait were aware that pesticides can be harmful to human health and to the environment if not applied correctly. However, although they knew about these effects, more than 70% of these farmers were still found to be applying chemicals without following the instructions indicated on the pesticide label (Jallow et al., 2017).

Some vegetable farmers are being reported to be harvesting vegetables within 7 days after pesticide application. Farmers growing cabbages in Ashanti region, Ghana were reported to be spraying pesticides during harvesting time, with no waiting period between application and harvesting (Amoako et al., 2012). This practice has led to death of people who consumed these vegetables contaminated with pesticides, whereas many of them have been reported sick and treated in hospitals (Anon, 2010). Farmers in Kuwait have increased pesticide use in their vegetables in order to control pests. In 2007, the level of pesticide use was 4.5 kg/ha (Bashour et al., 2017), and in 2015 the level had increased to 12.8 kg/ha (Jallow et al., 2017). This increased level of pesticide use can result in high levels of pesticide residues found in crops. World Health Organization promotes that vegetables must be included in the daily diet of humans (FAO/WHO, 2004). However, with the increased level of pesticide application, pesticide residues are more likely to be consumed by human in vegetables. Vegetable consumption with high level of residues can be harmful to human health (Elgueta et al., 2017). Pesticide residue consumption through vegetables can be the potential cause of chronic diseases to human beings (Lemos et al., 2016). Pesticide residue ingestion can cause diseases such as cancer, endocrine damage and it can also result in reproduction damage and other diseases (Berrada et al., 2010). Pesticide residues were found in high levels on fruits and vegetables in Gauteng Province, South Africa. Many of the pesticides found in those fruits and vegetables were not authorized to be used in agricultural production due to high amount of toxicity (Mutengwe et al., 2015). This can only mean that pesticides used by farmers must be monitored as well as the level of pesticide application by farmers.

There are strategies that can be used to reduce hazardous effects caused by poor pesticide application by farmers. Safety labels on the pesticide containers must be improved. Information indicating the uses and dangers about chemicals must be made clear to farmers.

Labels must indicate the dangers of the chemicals to human health and to the environment if handled poorly (Ajayi and Akinnifesi, 2007). Farmers in Cote d'lvoire have been assessed on their understanding of pesticide instructions indicated in the pesticide labels. Results indicated that majority of farmers usually misinterpret the instructions and the dangers of misusing the chemicals (Ajayi and Akinnifesi, 2007). This challenge results from poor literacy of farmers, lack of knowledge on the key pests and diseases and how to manage them and lack of awareness about the dangers that may result due to poor use of the chemicals (Ajayi and Akinnifesi, 2007; de Bon et al., 2014). There is a need to raise awareness to farmers about the meaning of instructions in safety labels and the dangers that may result due to poor pesticide practices.

Lack of capital also influences poor pesticide application. Smallholder farmers, especially those in developing countries do not have sufficient resources to purchase equipment used during pesticide application. Farmers in Ghana were found applying pesticides without knapsacks, instead, they were using brooms, brushes and tied leaves to splash chemicals as their way of spraying pesticides on crops (Afari-Sefa et al., 2015). Farmers can only reduce the level of pesticide use and pesticide residue if they practice integrated pest management (IPM). IPM was introduced in the late 1960s (Parsa et al., 2014). It has been introduced in order to reduce the level of pesticide use by farmers. However, its adoption by farmers in developing countries has been very slow. There are constraints that have limited the adoption and use of IPM by farmers. The most important constraints include lack of funding to implement IPM, insufficient training, lack of support to farmers and lack of significant evidence showing that IPM is effective in pest control (Parsa et al., 2014). There is a need for farmers to be well trained and educated about practicing IPM for pest control. This will help farmers to adopt and reduce their reliance of chemicals for pest control. This will also reduce the pesticide residues on crops and also reduce insecticide resistance by insect pests.

The major objective of this study was to evaluate pest control methods that farmers in Limpopo Province practice to manage insect pests on their vegetable crops.

5.2. Materials and methods

5.2.1. Description of study site

The study was conducted in South Africa, Limpopo Province in four municipalities of Vhembe District (22.7696º S, 29.9741º E). Vhembe District constitutes of four municipalities which are: Mutale (22.5108º S, 30.8039º E), Thulamela (22.8922º S, 30.6200º E), Makhado (23.0462º S, 29.9047º E) and Musina (22.3953º S, 29.6963º E). Within the district is Musina municipality which shares a border with Zimbabwe through the Beit bridge gate (Brournels, 2014). The population in this district is about 68.359 and the majority of this population number are black people (Stats, 2011). Vhembe District is characterised by semi-arid climates and it experiences dry spells with high temperatures throughout the year (Mpandeli, 2006). In some areas such as Musina municipality, rainfall ranges around 372 mm in summer seasons (Mpandeli, 2006) whereas rainfall is about 137 mm in Mutale municipality (Brournels, 2014). This district was chosen because it is known for experiences in high temperatures and erratic rainfall. These mean that farmers in this areas are more vulnerable to climatic changes. Vegetables such as tomatoes, cabbages, black nightshade and mustard spinach are the standard vegetables grown in this district. These vegetables are mostly grown in areas ranging from 1 hectare and above. Maize, and sweet potato are the main common field crops grown in Vhembe District. The most methods used for irrigation are drip irrigation and furrow irrigation for those who have access to water. In most of these municipalities, vegetables are rotated with field crops occasionally.

5.2.2. Study approach

Sampling concentrated on smallholder farmers found in rural areas and in peri-urban areas. Hundred and sixty-three farmers were selected randomly from a list of household farmers provided by extension officers. Quantitative data was collected using questionnaires. Qualitative data was collected through focus group discussions and key informants. Three focus groups were conducted in each municipality. This consisted of seven women alone, seven men alone and a combined group of seven men and seven women. Seven women and seven men were randomly selected from a list of farmers who did not participate in the questionnaire. Key informants selected in each municipality were extension officers and old age farmers familiar with the municipality. A checklist was used to collect qualitative data from key informants and focus.

5.2.3. Data analysis

The data was encoded in IBM Statistical Package for Social Sciences (SPSS) 23. Chi-square was used to compare the differences between different variables. Means and significant differences between means were declared at $P \leq 0.05$.

5.3. Results

5.3.1. Major crops grown in Vhembe District

Major crops grown differ according to municipality and landuse. Within the dryland systems, crops that were grown in all municipalities included: maize, sweet potatoes, black nightshade, tomatoes and mustard spinach. However, okra and groundnut crops were grown in Thulamela municipality (Table 5.1).

Within the irrigated system, crops grown in Thulamela, Mutale and Makhado municipalities were similar. In Musina, farmers grew crops which were different from what other municipalities grew. However, tomato crops were grown in the rest of the municipalities except Thulamela and Mutale municipalities. Tomatoes were widey grown in Musina municipality in areas ranging from one hectar to 1000 hectars (see Figure 5.1 below).

Table 5.1: Major crops grown in Municipalities according to landuse

Major crops		
Municipality	**Dryland**	**Irrigated**
Thulamela	Maize, cabbage, mustard spinach, okra, tomatoes, sweet potato, black nightshade, groundnuts	Maize, sweet potato, cabbage, green beans, black nightshade, mustard spinach, butternut, onions, groundnuts
Mutale	Mustard spinach, black nightshade, tomatoes, green beans, cabbage	Sweet potato, maize, sugar beans, cabbage, mustard spinach, black nightshade, onions
Makhado	Tomatoes, maize, sweet potato, pepper, black nightshade, mustard spinach, cabbage	Tomatoes, sweet potato, maize, sugar beans, ground nut, mustard spinach, black nightshade, cabbage, butternut
Musina	**N/A**	Tomatoes, butternut, water melon, okra, garlic, sweet melon

a 

b 

Figure 5.1: Tomato crops in Musina municipality
a. Tomato crops grown in large hectares, **b**. harvest of tomato fruits in Musina municipality

5.3.2. Control measures

In irrigated systems, Mutale (82.1%) and Makhado (82.8%) municipalities were not significantly different from each other, but were significantly different from the rest of the municipalities with respect to chemical control method (Figure 5.2). Cultural control methods were not used in Mutale and Makhado municipalities. With respect to mechanical methods, there was no significant difference between Musina municipality (10.07%) and Thulamela municipality (14.08%). Mechanical methods were not used to manage insect pests in Makhado and Mutale municipalities.

In dryland systems, all municipalities were not significantly different from each other with respect to chemical control methods ($P > 0.05$). Thulamela municipality (7.4%) and Makhado municipality (3.06%) were not significantly different from each other with respect to cultural methods (Figure 5.2). Cultural methods were not reported in Mutale municipality. Results from focus group discussions and key informants indicated that concussions were also used for insect pest control. Few farmers in Mutale irrigation system used *Tagetes minuta* to manage aphids and bagrada bugs. In Thulamela dryland system, farmers mentioned that they used two spoons of sunlight liquid soap mixed in 5 liters of water to manage insect pests.

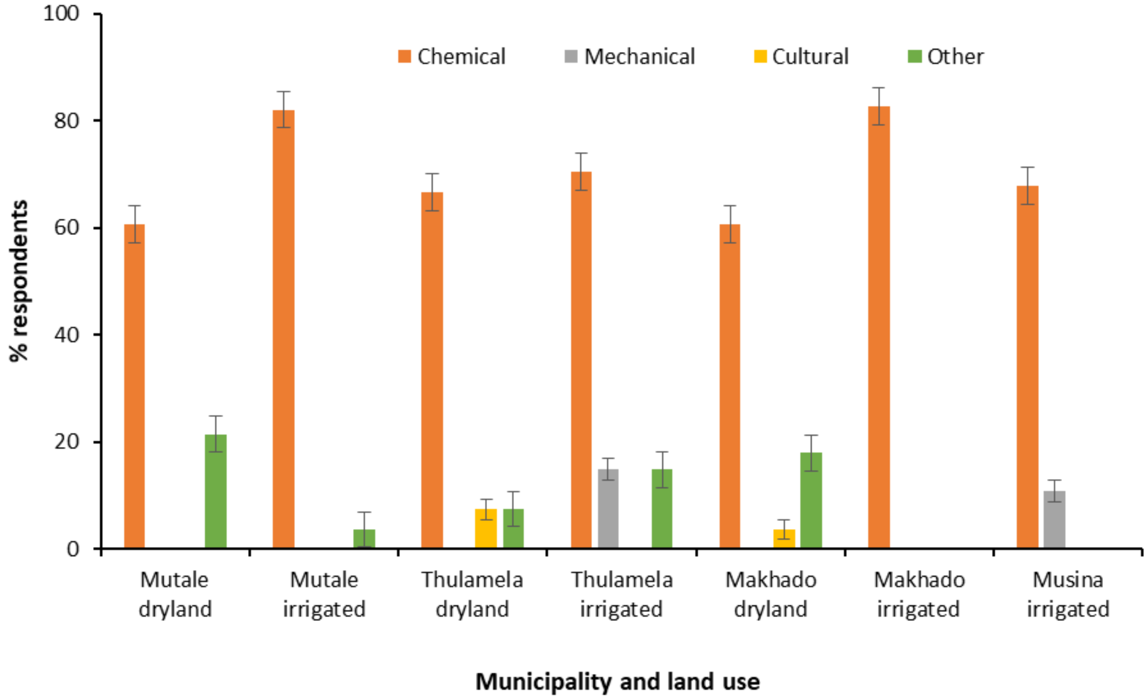

Figure 5.2: Control measures across municipalities and landuse
Bars represent standard error (SE) of the mean

5.3.3. Effectiveness of chemicals

In irrigated systems, all municipalities mentioned that chemical control was effective in managing pests and was significantly different from those who disagreed ($P < 0.05$) In dryland systems, only Makhado municipality (60.07%) disagreed that chemicals were effective in insect pest management (Figure 5.3).

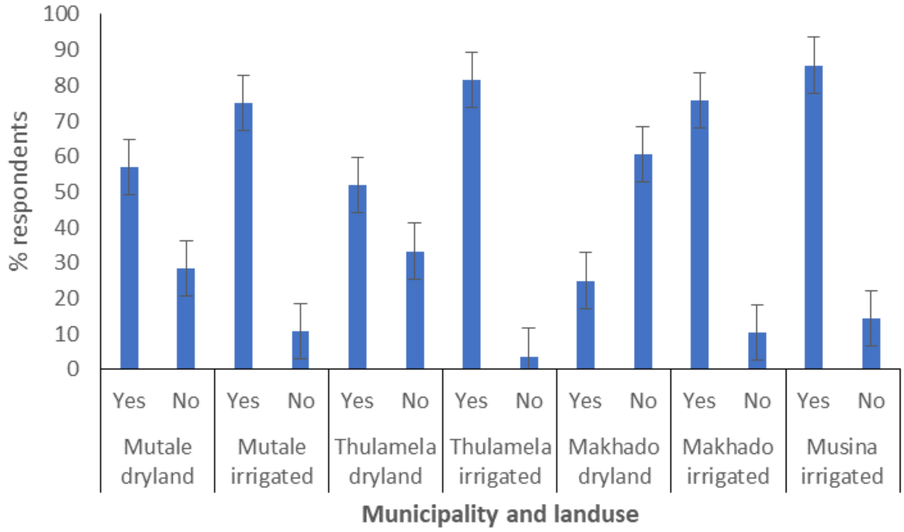

Figure 5.3: Effectiveness of chemical control
Bars represent standard error (SE) of the mean

5.3.4. Pesticide frequency application

In dryland systems, Makhado municipality (46.4%) was significantly different from Mutale (32.1%) and Thulamela (22.2%) municipalities with respect to chemical application once a week ($P < 0.05$) (Figure 5.4). With respect to chemical application three times a week, Thulamela municipality (37%) was significantly different from Mutale (7.1%) and Makhado (0%) municipalities. With respect to chemical application once a month, Thulamela municipality (7.4%) was significantly different from Mutale (14.3%) and Makhado (14.3%) municipalities which were not significantly different from each other.

In irrigated systems, with respect to chemical application once a week, Musina (53.6%) and Thulamela (44.5%) municipalities were significantly different from Mutale municipality (28.6%) and Makhado municipality (27.6%) which were not significantly different from each other. With respect to chemical application twice a week, Thulamela municipality was significantly different from the rest of the municipalities ($P < 0.05$). With respect to chemical application three times a week, Makhado municipality was significantly different from the rest of the municipalities which did not show any significant difference amongst themselves.

Within municipalities, chemical application once a week was significantly higher than the rest of the application frequencies in all municipalities and landuse, except Thulamela dryland system. Chemical application three times a week was significantly higher than the rest of the application frequencies in Thulamale dryland system.

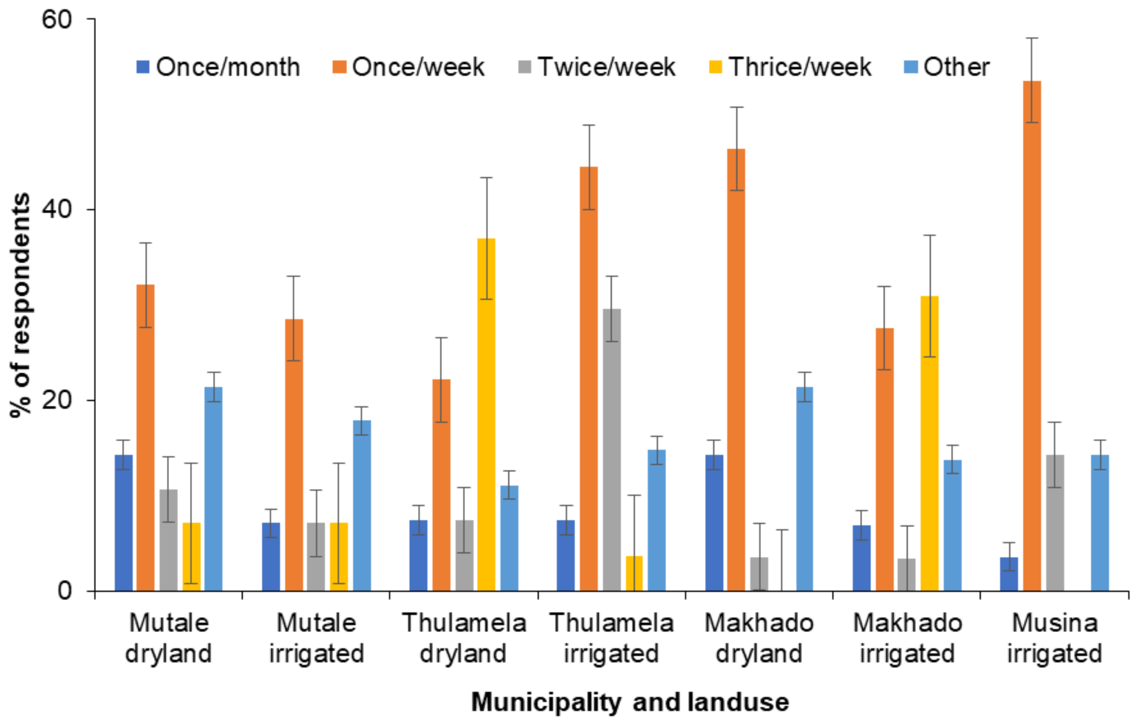

Figure 5.4: Frequency of spraying insecticides chemicals across municipalities and landuse
Bars represent standard error (SE) of the mean

5.3.5. Pesticide application frequency for the past 10 years

In all municipalities except Musina, farmers mentioned that there was no difference in pesticide application for the past 10 years and this was significantly different from those who agreed that there was a difference in pesticide application frequency (Figure 5.5). Results from focus group discussions also indicated that there was no difference in pesticide application frequency in the past ten years.

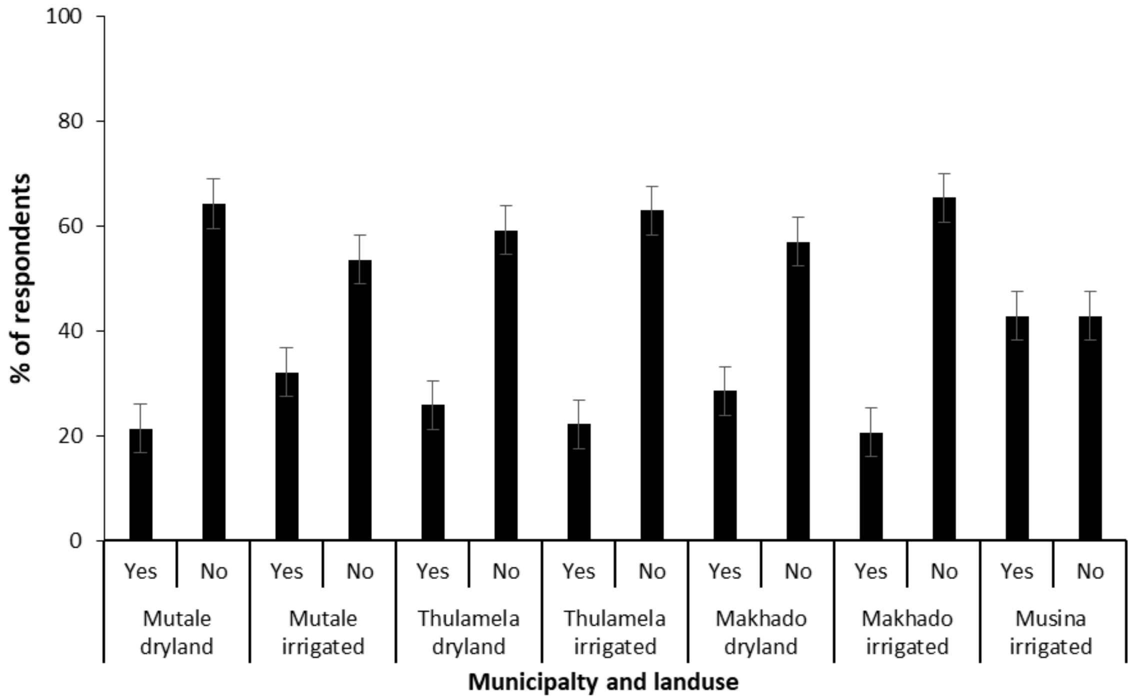

Figure 5.5: Application frequency for the past 10 years
Bars represent standard error (SE) of the mean

5.3.6. Rotation of chemicals

In dryland systems, farmers who rotated chemicals were significantly lower than farmers who did not rotate chemicals in all municipalities ($P < 0.05$) (Figure 5.6).

In irrigated systems, farmers who rotated chemicals in Thulamela (55.6%) and Musina (85.7%) were significantly higher than those who did not rotate chemicals ($P < 0.05$). In focus group discussions, dryland system farmers also confirmed that only few of them rotated chemicals. In Musina municipality, focus group discussions mentioned that majority of farmers did rotate chemicals.

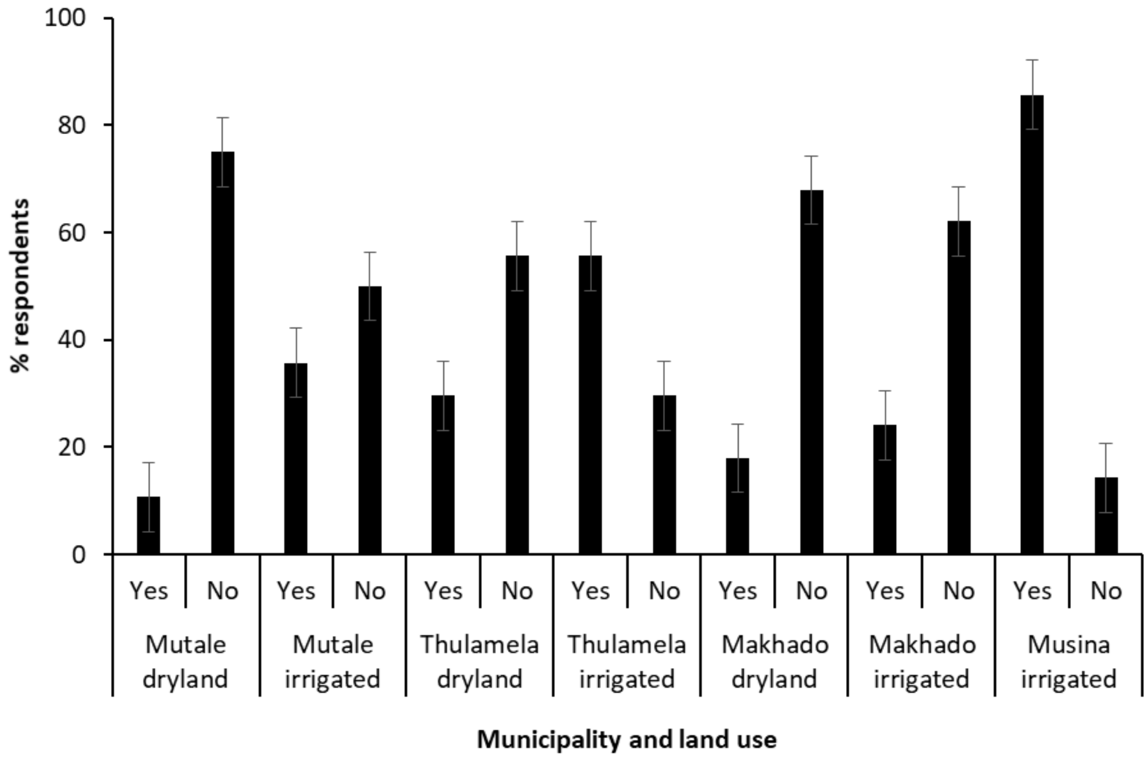

Figure 5.6: Rotation of chemicals in municipalities
Bars reprensent standard error (SE) of the mean

5.3.7. Reasons for pesticide rotation

In dryland systems, with respect to increasing pesticide efficiency, Thulamela municipality (25.9%) was significantly different from Mutale (3.6%) and Makhado municipalities (10.7%) which were not significantly different from each other (Table 5.2). With respect to no other alternatives, Makhado (3.6%) and Thulamela (3.7%) municipalities were not significantly different from each other ($P > 0.05$).

In irrigated systems, with respect to increasing pesticide efficiency, Musina municipality was significantly different from the rest of the municipalities, which did not show any significant difference amongst each other (Table 5.2). With respect to no other alternatives, Musina municipality (28.6%) was significantly different from the rest of the municipalities, which did not show significant difference amongst each other.

Table 5.2: Reasons for rotating chemicals

Reason	Mutale		Thulamela		Makhado		Musina
	Dryland	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**	**Irrigated**	**Irrigated**
To increase efficiency	3.6d	10.7d	25.9c	18.5d	10.7d	17.2d	35.7c
No other alternatives	0	0	3.7d	0	3.6d	0	28.6c
They are cheap	0	7.1d	0	0	0	0	10.7d
Control pests in many crops	0	0	3.7d	3.7d	0	3.4d	7.1d
No response	78.6a	53.6ab	29.6c	29.6c	67.9a	62.1a	3.6d
Other	3.6d	14.3d	3.7d	33.3c	3.6d	3.4d	0
STDEV	31.55	20.09	13.03	15.06	26.55	24.25	14.47

Means followed by the same letter are statistically similar at $P \leq 0.05$

5.3.8 Use of natural enemies for pest control/ biological control

All municipalities and their landuse systems farmers who did not use natural enemies to manage insect pests were significantly higher than those who used natural enemies ($P < 0.05$) (Figure 5.7).

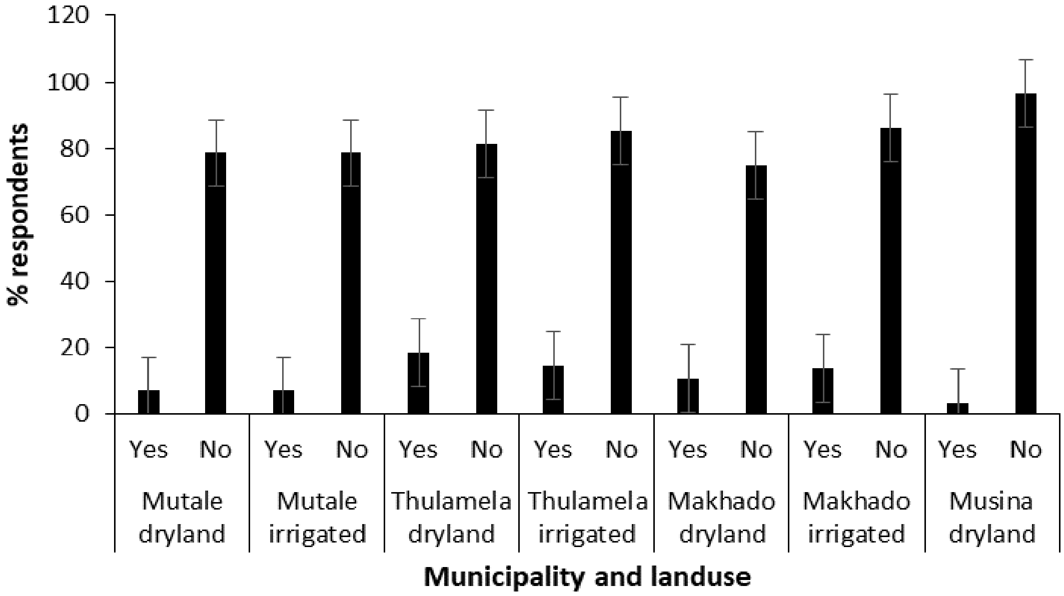

Figure 5.7: Use of natural enemies by farmers
Bars represent standard error (SE) of the mean

5.3.9. Effectiveness of natural enemies

All municipalities except Thulamela and irrigated system in Makhado municipality indicated that natural enemies were not effective because they were fewer. Both dryland and irrigated system of Thulamela municipality and irrigated system of Mutale municipality indicated that natural enemies did not feed on insect pests (Table 5.3). Only Mutale dryland and Thulamela irrigated municipality mentioned that natural enemies were overwhelmed by other pests such as aphids.

Table 5.3: None effectiveness of natural enemies (% of respondents)

Reason	Mutale municipality		Thulamela municipality		Makhado municipality		Musina municipality
	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated	Irrigated
Becoming fewer	3.6d	7.1d	0	0	3.6d	0	3.6d
Cannot feed on big insects	0	3.6d	3.7d	7.4d	0	0	0
Have developed many hosts	0	0	0	3.7	0	0	0
Control pests in many crops	0	0	0	0	0	0	0
Overwhelmed by aphid population	3.6d	0	0	7.4d	0	0	0
No response	53.6b	71.4a	74.1a	40.7b	82.1a	82.8a	96.4a
Other	25c	3.6d	7.4d	25.9c	0	3.4d	0
STDEV	20.30	26.22	27.45	15.36	30.83	31.11	36.23

Means followed by the same letter are statistically similar at $P \leq 0.05$

5.3.10. Chemicals used in controlling insect pests in irrigated and dryland landuse systems

In dryland systems, malasol insecticide was signifcantly different from cypermethrin insecticide in Thulamala municipality and Mutale municipality ($P < 0.05$) (Figure 5.8). In vegetables, the most used chemical in Makhado municipality and Thulamela was malasol. Tamaron (20%) was the most used chemical to control vegetable pests in Mutale municipality.

In irrigated systems, the most used chemical in maize was Dipterex (71%) followed by Cypermethrin (66.64%). In vegetables, the most used chemical was Cypermethrin (66.64%), followed by Tamaron (42.8%) and Malasol (28%). The most used chemicals in sweet potato in irrigated systems was steward (14.02%) and Malathion (8%). Within municipalities, in

Thulamela irrigated, the most used chemical was Dipterex (71%) followed by Cypermethrin (61.6%) (Figure 5.8).

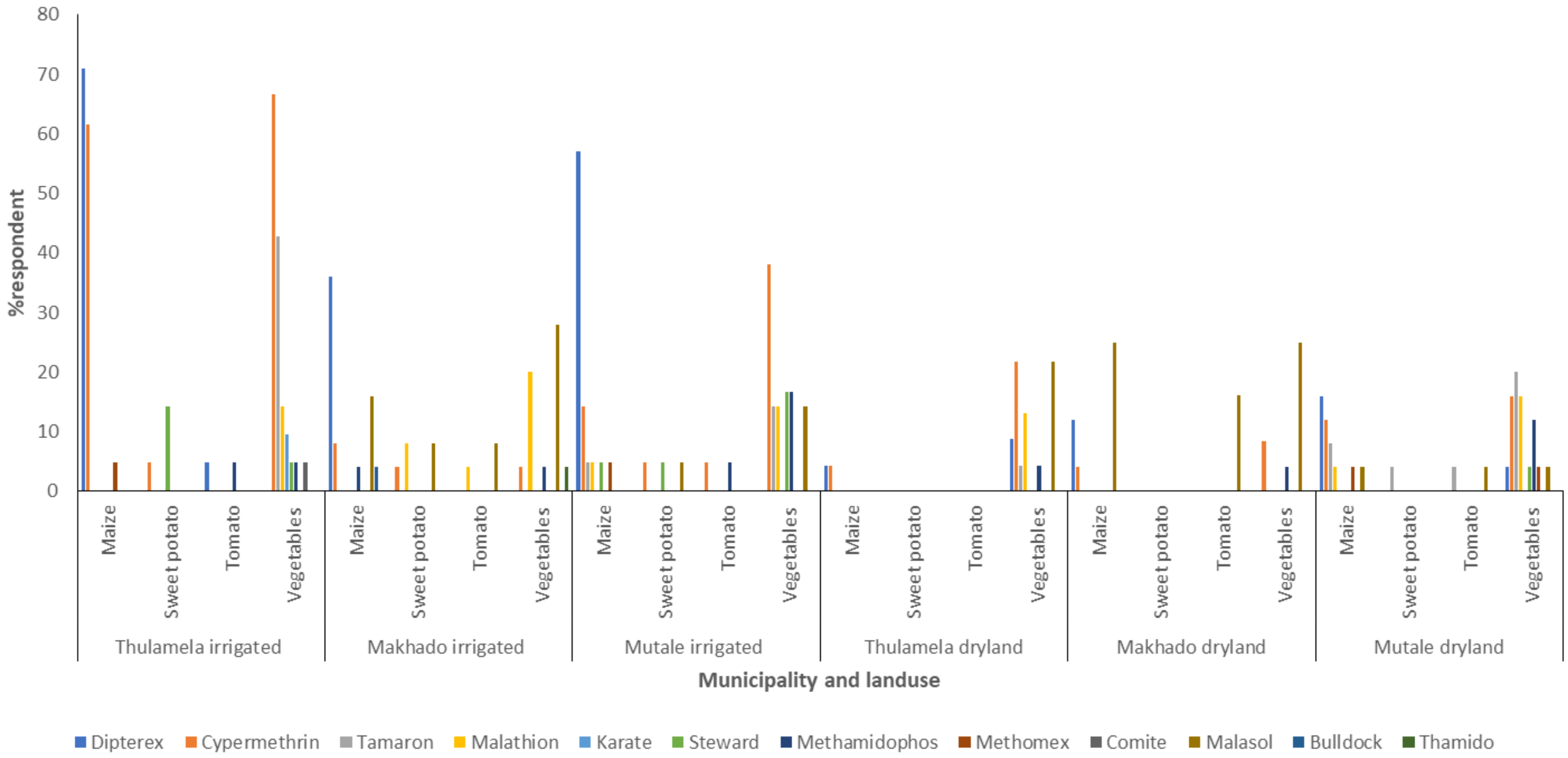

Figure 5.8: Chemicals used in controlling pests

5.3.11. Chemicals used in Musina municipality to manage pests

The most used chemical in Musina municipality was Cypermethrin (50%) followed by steward (45.83%). In tomatoes, Steward is the most used chemical (45.83%) followed by Methomex (28.83%) (Figure 5.9). The least used chemicals were Karate and Methamidophos (4.16%). In vegetables the most used chemical was Cypermethrin (41.66%) followed by Methamidophos (16.66%). The least used was Kohinor (12.05%) and steward (4.16%). In Maize the most chemical used was Cypermethrin (50%) followed by steward (12.05%).

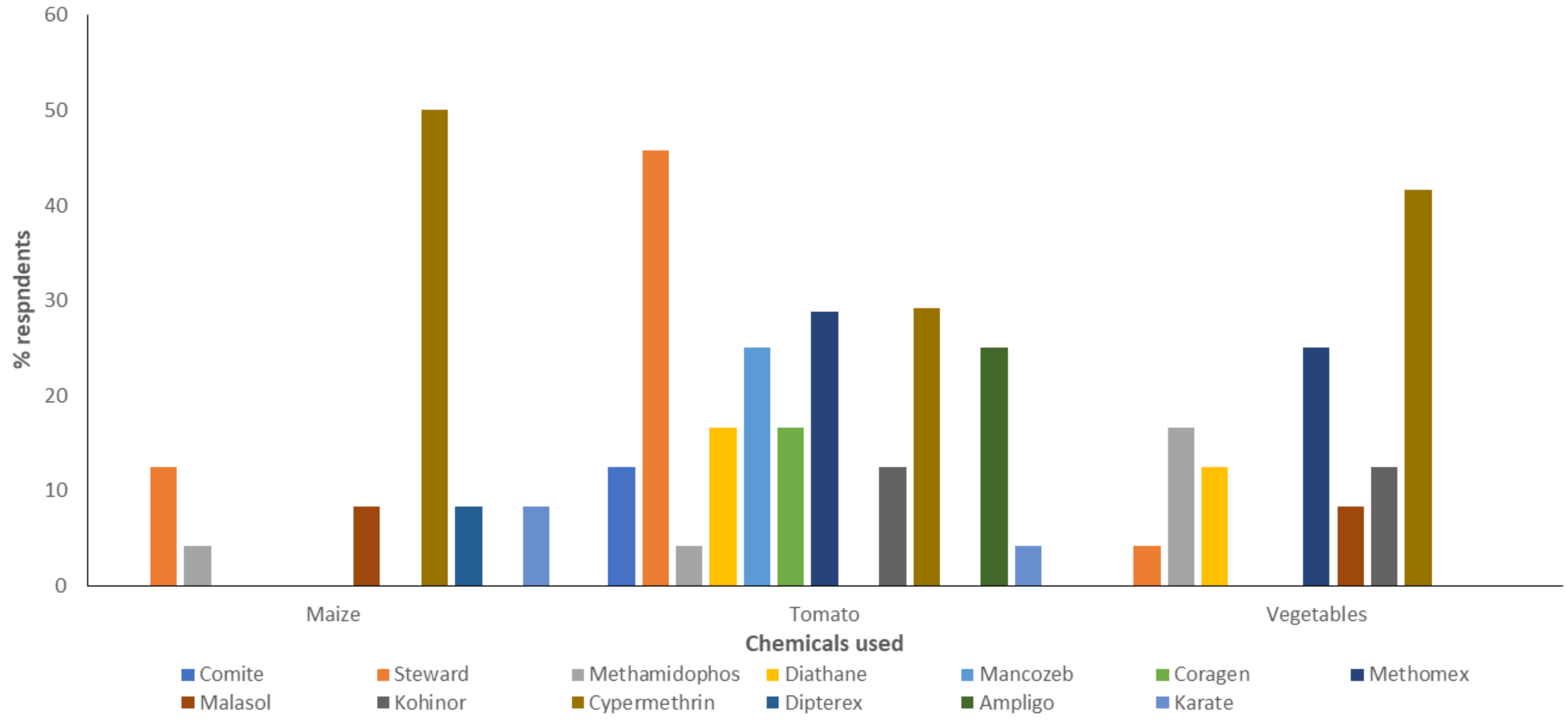

Figure 5.9: Chemicals used in Musina municipality

Amongst the pesticide used by farmers in both irrigated and dryland system, tamaron, metamidofos, and thamido had the same active ingredient (Table 5.4).

Table 5.4: Common name and active ingredients of insecticides used

Common name of pesticide	**Active ingredient**
Dipterex	Trichlorfon
Cypermethrin EC	Cypermethrin
Tamaron	Methamidophos
Malathion	Mecaptothon
Karate	Lambda-cyhalothrin
Steward	Indoxacarb
Methamidofos	Methamidophos
Methomex	Methomyl
Malasol	Mercaptothion
Bulldock	Beta-cyfluthrin
Thamido	Methamidophos
Comite	Propargite
Kohinor	Imidachloprid
Diathane	Mancozeb
Coragen	Rynaxypr
Ampligo	Lambda-cyhalothrin

5.4. Discussion

The commonly grown crops in all municipalities were maize and sweet potato in both irrigated and dryland systems with exception of Musina muncipality. Maize is known to be the most staple crop grown in Africa. Limpopo Province is characterized by hot and dry conditions. These crops are usually grown in summer season. Farmers in Limpopo experience summer rainfall (Tshiala, et al., 2012). This is an advantage to farmers who depend highly on rainfall for their crops. Limpopo Province is said to have areas, which are potentially suitable for dryland crop production (Tshiala et al., 2012). Black nightshade is one of the traditional vegetables consumed by people in South Africa (Mampholo et al., 2016). This is why it was widely grown in both irrigated and dryland systems of Vhembe District municipalities. This crop does not require much management and it can tolerate adverse conditions (Mampholo et al., 2016). Black nightshade vegetable contains protein, vitamins and other minerals such as calcium and potassium (Van Averberke et al., 2007). Tomatoes were widely grown in Makhado and Musina municipalities. Limpopo Province produces 66% tons of tomatoes annually (NDA, 2009).

Both dryland and irrigated farmers of vegetable and field crops in Limpopo Province highly depended on chemical control to manage insect pests. This might have been influenced by increased pressure of insect pests in the region. The other reason could be that chemical control requires less labour compared to other control measures (Okolle et al., 2016). It has been revealed that many farmers in developing countries, especially in rural areas depend highly on chemical control for pest management (Fischel, 2007). There are other control measures such as biological, cultural and integrated pest management that farmers can use to reduce high dependence of chemicals. However, farmers in Limpopo Province used chemical control significantly than other control methods. The reason could be that farmers were not receiving enough service delivery from extension services and alternate advisory service providers. Therefore, they were not fully trained on how to apply other control methods thus increasing reliance of chemicals for insect pest control. Ngowi (2003) mentioned that lack of extension services to farmers on different pest control methods can influence high reliance of pesticides for pest control. This was also the case with the farmers in this study; they indicated that they hardly received extension services regarding proper farming skills. Other studies indicated that many extension services from the government encourage farmers to use pesticides for pest control than other methods (Abate et al., 2000). Majority of farmers mentioned that chemical control was effective for insect pest management. This could be because farmers had no or little knowledge on how effective other methods can be in pest management. This indicates that these farmers were not aware that other methods are environmentally friendly, inexpensive and can be effective for pest control if applied correctly. No farmers used natural enemies for pest management. The reason behind this was lack of training from extension and little knowledge about this method. However, natural enemies could be available in their farms, but due to lack of knowledge, farmers might be killing them with chemicals during application. This explains why farmers reported that natural enemies were not effective in insect pest reduction.

Pesticide application once a week resulted from the instructions labelled on most chemicals. Farmers indicated that most chemical labels indicated an interval of 7 days to the next application. However, in focus group discussions, most farmers indicated that they applied chemicals every seven days even when no pests were seen on crops. This means that farmers did not scout for insect pests before pesticide application. Some depended on their calendar programmes for pesticide application. The calendar showed them when to start applying and at what stage of crop should they stop pesticide application. This is why most farmers did not change their application for the last 10 years. Epstein and Bassein (2003) reported that farmers depend highly on calender programs for pesticide applications irrespective of the consequence of chemicals to the environment. Some farmers applied chemicals three times a week. According to focus group discussions, they indicated that if pests were not dying, they continued spraying chemicals for effective control. It can be suspected that insect resistance has risen due to poor application methods. Carvalho (2006) reported that increased pesticide application can lead to high risks of insect resistance. These means that farmers over applied chemicals for pest control. There are other studies that confirmed that most farmers in developing countries misused and overused chemicals for insect pest control (Wilson and Tisdell, 2001). This problem has also been reported in Kuwait, were 58% of smallholder farmers growing vegetables overused pesticides for insect pest control (Jallow et al., 2017). Overusing pesticides can also result to high rates of pesticide residues on crops. This is harmful to human health and can lead to chronic diseases such as cancer (Berrada et al., 2010). This means that farmers in Limpopo Province will be risking their health if high pesticide residues could be found in their crops.

Farmers in all municipalities except Musina and Thulamela irrigated system, did not rotate chemicals. There was lack of knowledge on other types of insecticides that farmers could use.

Due to lack of advisory services, farmers continued using the chemicals they knew. According to focus group discussions, government did supply chemicals to farmers. However, farmers rely only on those chemicals for pest control, and that is the reason behind why majority of farmers did not rotate chemicals. Musina municipality was dominated by farmers who grew tomatoes on a large scale. Rotation of chemicals was practiced due to high resistance levels of insect pests. Farmers in Musina municipality agreed that they received advisory services and that they were more knowledgeable about pesticides than other municipalities. Therefore, they understood the need to rotate chemicals in order to reduce levels of resistance. However, during focus group discussions, farmers mentioned that they did not always follow the precautions when applying chemicals. Some farmers did not wear safety clothes and masks during pesticide application. Farmers tended to ignore that pesticides are harmful to their health. Palis et al (2006) indicated that most farmers believed that pesticides can only be harmful to the weak and the old. There was lack of understanding on the harmful impact of hazardous pesticides.

Chemicals mostly used were mathion, malasol, cypermethrin, methamodiphos and tamaron in all municipalities except Musina. Farmers knew these chemicals by brand names or common names. Results indicated that most farmers were not knowledgeable about the active ingredients in chemicals. Malathion and malasol have the same active ingredient (mecarptothion) and they are less harmful (NDA, 2009). Pesticides referred to as methamodiphos and tamaron are also amongst the mostly used by farmers and are regarded as extremely hazardous, belonging to group 1b ranked by WHO (Jallow et al., 2017). This indicated that farmers were not aware of which insecticides were hazardous to them and to the environment. Farmers were putting their health at risks, especially those who did not follow safety precautions during pesticide application. Cypemethrin is moderately hazardous. Karate has lambda-cyhalothrin, which is moderately hazardous (Jallow et al., 2017). Farmers also used coragen, which was less harmful. This chemical was made to control moths such as leaf miner and other problematic moths (Bassi et al., 2009). It is not harmful to non-target insects such as pollinators and soil microorganisms (Dinter et al., 2008). The danger of hazardous chemical is that they can lead to cancer, immune system disorders, and can be harmful to pregnant women, and may cause other minor diseases (Amera and Abate, 2008).

5.5. Conclusion

The study has documented the types of pest control measures that were widely used by farmers in Vhembe District. This study showed that the most used control measures for pest management were chemicals. This study also showed that these farmers were not fully knowledgeable about pesticide use and the effects it has on the environment as well as on their health. Farmers were aware of the chemicals they used but they did not understand the issue of active ingredients in pesticides. The majority of farmers identified the chemicals by brand names. This could be due to lack of advisory services from extension, NGOs and private sector. Therefore, there is need for farmers to be trained on pesticide use and how to identify pesticides by their active ingredients. Farmers should also be trained on when to apply chemicals and when to stop applying chemicals. Further studies need to be conducted on the pesticide residues in vegetables and other field crops. Farmers need to be trained on other pest control measures such as biological, cultural, IPM in order to reduce reliance on pesticides for pest control. This will also reduce hazardous effects on the environment and farmer’s health.

References

Abate, T., van Huis, A., & Ampofo, J.K.O. (2000). Pest management strategies in traditional agriculture: an African perspective. *Annual Rev. of Entomology, 45,* 631-659

Addo, S., Birkinshaw, L.A., & Hodges, R.J. (2002). Ten years of the arrival of larger grain borer: farmer's responses and adoption to IPM strategies. *International Journal of Pest Management, 48,* 315-325

Afari-Sefa, V., Rajendran, S., Kessy, R. F., Karanja, D. K., Musebe, R., Samali, S., & Makaranga, M. (2016). Impact of nutritional perceptions of traditional African vegetables on farm household production decisions: A case study of smallholders in Tanzania. *Experimental Agriculture, 52,* 300-313

Ahouangninou, C., Martin, T., Edorh, P., Bio-Bangana, S., Samuel, O., St_Laurent, L., Dion, S, & Fayomi, B. (2012). Characterization of health and environmental risks of pesticide use in market-gardening in the rural city of Tori-Bossito in Benin, West Africa. *Journal of Environmental Protection, 3,* 241–248

Ajayi, O.C., & Akinnifesi, F.K. (2007). Farmer's understanding of pesticide safety labels and field spraying practices: a case study of cotton farmers in northern Cote d'lvoire. *Scientific Research and Essay, 2,* 204-210

Aktar, M.W., Sengupta, D., & Chowdhurry, A. (2009). Impact of pesticide use in agriculture: their benefits and hazards. *Interdisciplinary Toxicology, 2,* 1-12

Amera, T., & Abate, A. (2008). An assessment of the pesticide use, practice and hazards in the Ethiopian rift valley. *The First African congeress in pesticide and toxicology Science,* Waddani, Sudan

Amoako, P.K, Kumah P., & Appiah, F. (2012). Pesticides usage in Cabbage (*Brassica oleracea*) Cultivation in the Ejisu-Juaben Municipality of the Ashanti Region of Ghana. *International Journal of Research in Chemistry and Environment 2,* 2631

Anon, (2010). Ghana: Twelve die after poisonous food', 4 December 2010, www. afriquejet.com

Ashburner, J., & Friedrich, T. (2001). Improving handling of pesticide application equipment for the safety of applicators. *Pesticide management in west Africa newsletter no 2. FAO/ economic community of west African states.* Accra, Ghana pp 9-11

Bashour I. Pesticides, fertilizers and Food Safety. In: Tolba M.K., Saab N.W., editors. Arab Environment Future Challenges. Arab Forum for Environment and Development; Beirut, Lebanon: 2008. pp. 137–145

Bassi A., Molnar I., Zielinski D., Savulescu I., Shulgan V., Denic I., Allin J. & Rison J.L. (2009). Chlorantraniliprole (Rynaxypyr®, Coragen®): a novel anthranilic diamide insecticide with outstanding control of Colorado potato beetle (Leptinotarsa decemlineata). Proceedings of the 17th Triennial Conference of the EAPR – *International Potato Conference,* 475- 478

Berrada H, Fernandez M, Ruiz MJ, Molto JC, Manes J, & Font G. 2010. Surveillance of pesticide residues in fruits from Valencia during twenty months (2004/2005). *Food Control 21,* 36–44

Brournels, M. (2014). The local government handbook of South Africa 2014: a complete guide to municipalities in South Africa, 4th edistion. Yes! Media, Calermount, RSA, Pp. 2015

Carvalho, E.P. (2006). Agriculture, pesticides, food security and food safety. *Environmental Science and policy, 9,* 685-692

Cock, M.J.W., Beseh, P.K., Buddie, A.G., Cafa, G. & Crozier, J. (2017). Molecular methods to detect *Spodptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. *Scientific Reports, 7,* 4103

DAFF. (2015). A profile of the South African cabbage market value chain: Department of Agriculture, Forestry and Fisheries. Acardia, South Africa. http://www.nda.agric.za

de Bon, H., Huat, J., Parrot, L., Sinzogan, A., Martin, T., Malezieux, E., & Vayssieres, J.F. (2014). Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa A review. *Agronomy and Sustainable Development, 34*, 723-736

Dinham, B. (2003). Growing vegetables in developing countries for local urban populations and export markets: problems confronting small-scale producers. *Pest Management Science, 59,* 575-582

Dinter A., Brugger K., Bassi A., Frost N.M. & Woodward, M.D. (2008). Chlorantraniliprole (DPX-E2Y45, Rynaxypyr®) (Coragen® 20SC and Altacor® 35WG) – a novel DuPont anthranilic diamide insecticide – demonstrating low toxicity and low risk for beneficial insects and predatory mites. *IOBC WPRS Bulletin, 35,* 128-135

Drescher, A. (2001). The integration of Urban Agriculture into urban planning – An analysis of the current status and constraints. *Annotated Bibliography on urban agriculture.* ETC-RUAF. CTA, Wageningen Netherlands

Ecobichon, D. J. (2001). Pesticide use in developing countries. *Toxicology, 160,* 27–33

Elgueta, S., Moyano, S., Sepúlveda, P., Quiroz, C., & Correa, A. (2017). Pesticide residues in leafy vegetables and human health risk assessment in North Central agricultural areas of Chile. *Food Additives & Contaminants: Part B, 10,* 105-112

Epstein, L., & Bassein, S. (2003). Patterns of pesticide use in Carlifonia and the implications for strategies for reduction of pesticides (Review). *Annual Review of Phytopathology, 41,* 351-375

FAO/WHO. (2004). Vitamin and mineral requirements in human nutrition. Food and Agricultural Organisation, Rome. Retrieved from http://www.fao.org

Fishel, f.M. (2007). Pesticide use trends in the US: Global comparison. Florida Cooperative Extension Service, University of Florida, Publication p1-143, pp 3

Hashemi, S.M., Rostami, R., Hashemi, M.K., & Damalas, C.A. (2012). Pesticide use and risk perceptions amongst farmers in Southwest Iran. *Human and Ecological Risk Assessment, 18,* 456-470

Jallow, M. F. A., Awadh, D. G., Albaho, M. S., Devi, V. Y., & Thomas, B. M. (2017). Pesticide risk behaviours and factors influencing pesticide use among farmers in Kuwait. *Science of the Total environment, 574,* 490-498

Lemos, J., Sampedro, M.C., Ariño, A., Ortiz, A., & Barrio, R.J. (2016). Risk assessment of exposure to pesticides through dietary intake of vegetables typical of the Mediterranean diet in the Basque Country. *Journal of Food Compost Anal. 49,* 35–41

Mampholo, B. M., Sivakumar, D., & Thompson, A. K. (2016). Maintaining overall quality of fresh traditional leafy vegetables of Southern Africa during the postharvest chain. *Food Reviews International, 32,* 400-416

Matthews, G., Wiles, T., & Baleguet, P. (2003). A survey of pesticide application in Cameroon. *Crop Protection 22,* 707-714

Mazlan, N., & Mumford, J. (2005). Insecticide use in cabbage pest management in the Cameron Highlands, Malaysia. *Journal of Crop Protection 24,* 31-39

Mpandeli, S.N. (2006). Coping with climate variability in Limpopo Province. Unpublished PhD thesis, University of Witwatersrand lessons from southern Africa. *South African Journal of Science, 105,* 34-49

Mutengwe, M.T., Chidamba, L., & Korsten, L. (2016). Monitoring pesticide residues in fruits and vegetables at two of the biggest fresh produce markets in Africa. *Journal of Food Protection, 79* 1938-1945

NDA (2009). Directorate: Agricultural Statistics Section. Pretoria, South Africa

Ngowi, A.V.F. (2003). A farmer's knowledge, attitude and experience in the use of pesticides in coffee farming. *African newsletter on Occupational health safety, 13,* 62

Ngowi, A.V.F., Mbise, T.J., Ijani, A.S.M., London, L., & Ajayi, O.C. (2007). Smallholder vegetable farmers in Northern Tanzania: pesticides use practices, perceptions, cost and health effects. *Crop Protection, 26,* 1617-1624

Ntow, W.J., Gijzen, H.J., kelderman, P., & Drechsel, P. (2006). Farmer perceptions and pesticide use practices in vegetable production in Ghana. *Pest Management Science, 62,* 356-365

Oerke, E.C. (2006). Crop losses to pests. *Journal of Agricultural Science, 144,* 31-43

Okolle, N.J., Afari-Sefa, V., Bidogeza, J.,Tata, P.I., and Ngome, F.A. (2016). An evaluation of smallholder farmers' knowledge, perceptions, choices and gender perspectives in vegetable pests and diseases control practices in the humid tropics of Cameroon. *International Journal of Pest Management, 62*, 165-174

Oliveira, C.M., Auad, A.M., Mendes, S.M & Frizzas, M.R. (2014). Crop losses and the economic impact of insect pests on Brazilian agriculture. *Crop Protection, 56,* 50-54

Palis, F.G., Flor, R.J., Warburton, H., & Hossain, M. (2006). Our farmers at risk: Behaviour and belief system in pesticide safety. *Journal of Public Health*, *28,* 43–48

Parsa, S., Morse, S., Bonifacio, A., Chancellor, T.C.B., Condori, B., Crespo-Perez, V., Hobbs, S.L.A., Kroschel, J., Ba, M.N., Rebaudo, F., Sheerwood, S.G., Vanek, S.J., Faye, E., Herreva. M.A., & Dangles, O. (2014). Obstacles to integrated pest management adoption in developing countries. *PNAS, 11,* 3889-3894

Pretty, J., & Waibel, H. (2005). Paying the price: the full cost of pesticides J. Pretty (Ed.), The Pesticide Detox. Towards a More Sustainable Agriculture, Earthscan, London pp. 39-54

Schreinemachers, P., & Tipraqsa, P. (2012). Agricultural pesticides and land use intensification in high, middle and low income countries. *Food Policy, 3,* 616- 626

Sibanda, T., Dobson, H.M., Cooper, J.F., Manyanyangarirwa, W., & Chiimba, W. (2000). Pest management challenges for smallholder vegetable farmers in Zimbabwe. *Crop Protection 19,* 807-815

Stats SA (2011). Census 2011: Provincial profile: Limpopo/ Statistics South Africa. http://www.Stats Sa.gov.za/publications/report-03-01-78/report-03-01-782011

Tolosana, S., Rother, H., & London, L. (2009). Child's play: exposure to household pesticide use among children in rural, urban and informal areas of South Africa. *South African Medical Journal, 99,* 180-184

Tshiala, M.F., Botai, F.O., & Olwoch, J.M. (2012). Leafminer agromyzed pest distribution over Limpopo Province under changing climate. *African Journal of Agricultural Research, 7,* 6515-6522

Van Averbeke, W., Juma, K. A., & Tshikalange, T. E. (2007). Yield responses of African leafy vegetables to nitrogen, phosphorus and potassium: The case of *Brassica rapa* L. Subsp, *Chinensis* and *Solanum retroflexum* Dun. *Water SA, 33*, 355-362

Williamson, S., Ball, A., & Pretty, J. (2008). Trends in pesticide use and drivers for safer pest management in four African countries. *Crop Protection, 27,* 1327-1334

Wilson, C. I, & Tisdell, C. (2001). Why farmers continue to use pesticides despite environmental, health and sustainability cost. *Ecology and Economy, 39,* 446-449

Xu, R., Kuang, R., Pay, E., Dou, H., & de Snoo, G. R. (2008). Factors contributing to overuse of pesticides in western China. *Environmental Sciences, 5*, 235- 249

Yousefi, Z. (2008). A survey of pesticide toxicant utilization from Caspian Sea banks, Mazandaran Province, Northern Iran. *Environmental Justice, 1,* 101–106

CHAPTER 6: THE ROLE OF INSTITUTIONS IN SUPPORTING PEST MANAGEMENT AND SMALLHOLDER AGRICULTURE

Abstract

Pests of vegetables are major constraints to farmers in Limpopo Province. The damage caused by insect pests result in great yield losses in Limpopo Province. These insect pests are exacerbated by poor use of pesticides, climatic change factors such as high temperature and late rainfall. This study was conducted to evaluate the role of institutions in farmer's pest management constraints in Limpopo Province. Quantitative and qualitative data collection methods were used for data collection. Farmers highlighted major issues such as input supply from the government and water availability. With respect to extension, farmers wanted extension services to be rendered. Farmers also highlighted that researchers must return their research findings after completion of researches. Therefore, participatory research approaches need to be implemented in Limpopo Province for sustainable agricultural production. There is a need for pluralism in extension services, research and government input supply.

Keywords: extension services, government services, research, pluralism, participatory approach

6.1. Introduction

Sustaining recent growth in African agriculture is essential for the continent's ability to achieve food security and maintain broader economic growth in the future. Fast rising-food demand from the growing and urbanizing population presents an opportunity for African smallholder farmers, if they can ensure the required productivity and production increase. However, the effects of climate change threaten farmer's ability to maintain and accelerate agricultural growth. New and emerging pests and diseases under climate change pours a threat to agricultural productivity and food security (Phophi and Mafongoya, 2017).

Smallholder agricultural producers in Africa face numerous challenges (Poulton et al., 2010). Research into technologies appropriate to the agro-conditions of farmers and increase investment in basic infrastructure (roads, communication and irrigation) to these areas are both necessary if they are to enhance their livelihoods in the years to come. Land tenure and water rights regimes that combine a concern for equity with security for investors are also necessary, if not sufficient conditions for broad-based agricultural growth. Along these, efficient pre- and post-harvest services are crucial for the future farmers. They are essential if small farms in high potential areas are to intensify their production, e.g. irrigation schemes, as they contribute to national economic growth and poverty reduction. They are also essential for farmers in marginal areas (Semi-arid or remote area) if they were to manage their natural resources. These will help to sustain per capita agricultural production despite growing population pressure and climate change.

6.1.1. Research and extension services

Since the 1980s, research and extension have been neglected and smallholder agriculture has not received adequate priority at national level (Evenson, 2001). There is a need for increasing investment in high quality research and advisory extension services that are coherent with models of production adapted to farmer's needs. Research must address a more complex set of objectives and new challenges (climate change, energy, environment and natural resource management) as well as old ones (productivity and production) and promote diversification on food and nutritional security (HLPE, 2012). The key message is to break the vicious cycle of "Poor research and extension for poor farmers".

National research and extension services need full attention and investment from government and donor community. Research should include partnership with producer associations, NGOs and farmers. Research has to develop local adapted genetic materials, which can produce in difficult conditions, development of low cost technologies, promotion of diversification of production systems and research to increase value addition at farmer level.
Food crops and the nutrition issue should receive the highest priority form research. Productive partnerships between international and national research centers must give priority to these food crops, which are neglected and underutilized. Processing of food, aiming at better adoption to market transformation for urban use, must receive support form researchers in order to improve efficiency in productivity and the equipment and method used.

Ecological models that optimize sustainable management of natural resources and ecosystem services are particularly promising for smallholder farmers (IAASTD, 2009). The fact that agroecological approaches are often knowledge intensive and need to be adapted to local conditions implies the need for collective and public investment as private sector focuses on a limited range of technologies that are profitable for them. Public investment in breeding programmes and support for local seed systems that allow the diffusion of genetic materials which farmers would have the right to save, exchange and market is a good example of the need of public investment in research (Arrow and Lind, 2014).

Research that promote the uptake of agro-ecological principles with conventional practices to minimize the use of synthetic pesticides and fertilizers is highly needed (Barzman et al., 2014). More research is also needed in the socio-economic side to better understand smallholder agriculture. Research that involves smallholder farmers in the definition of research priorities, the design and execution of research according to participatory and empowering methodologies is crucial. This is the best way to ensure that research result respond to complex, social and economic, as well as ecological contexts of smallholder farmers. To achieve this, research systems must be well accounted to smallholder farmers in terms of their institutional priorities, the impact of their work and their funding (Magoro and Hlungwani, 2014).

The primary objectives associated with agricultural extension and advisory services are concerned with transferring technologies associated with major crop and livestock production systems and enhancing skills and knowledge (human capital) among all types of farmers and rural families. This can allow them to select more appropriate mix of crop and livestock enterprises and use the most efficient production management practices, for improving rural livelihoods and achieving household food security. This is achieved by increasing farm household income, nutrition, education and strengthening natural resource management in each country. It is important to recognize that the role and structure of extension and advisory systems will continue to change and evolve as the agricultural development process changes in each country.

Extension consist of public and private sectors and their major duty is to disseminate education to farmers (Marsh and Pannell, 2000). One of the important function of extension is to link farmers to market and researchers to assist in providing sustainable agriculture (Poncet et al., 2010). Extension is also responsible for training farmers on issues such as good agricultural production, agro-processing, climate change adaptation (Chowa et al., 2013). Training is made possible through study tours, classroom training sessions, village meetings with farmers (Chowa et al., 2013). However, extension has many challenges in rendering services to farmers, especially those in developing countries (Birner et al., 2009). Lack of funds to run these services to farmers is one of the major challenge that extension face. In Democratic Republic of Congo, extension has been failing to disseminate knowledge and to conduct training to smallholder farmers due to lack of funds (Ragasa et al., 2016). Extension also has lack of transport to use when visiting farmers. In most developing countries, motorbikes are used as a mode of transport to visit farmers for service rendering. However, many extension workers still fail to access motorbikes from their work place to visit farmers (Ragasa et al., 2016).

The main objective of this study was to evaluate farmer's perceived roles of government, research and extension services in supporting them to manage emerging and new pests in vegetable production. The general support of government to smallholder agriculture was also an objective to this study.

6.2. Materials and methods

6.2.1. Description of study site

The study was conducted in South Africa, Limpopo Province in four municipalities of Vhembe District (22.7696° S, 29.9741° E). Vhembe District constitutes of four municipalities which are: Mutale (22.5108° S, 30.8039° E), Thulamela (22.8922° S, 30.6200° E), Makhado (23.0462° S, 29.9047° E) and Musina (22.3953° S, 29.6963° E). Within the district is Musina municipality which shares a border with Zimbabwe through the Beit bridge gate (Brournels, 2014). The population in this district is about 68.359 and the majority of this population number are black people (Stats, 2011). Vhembe District is characterized by semi-arid climates and it experiences dry spells with high temperatures throughout the year (Mpandeli, 2006). In some areas such as Musina municipality, rainfall ranges around 372 mm in summer seasons (Mpandeli, 2006) whereas rainfall is about 137 mm in Mutale municipality (Brournels, 2014). This district was chosen because it is known for experiences in high temperatures and erratic rainfall. This mean that farmers in these areas are more vulnerable to climatic changes. Vegetables such as tomatoes, cabbages, black nightshade and mustard spinach are the standard vegetables grown in this district. These vegetables are mostly grown in areas ranging from 1 hectare and above. Maize, and sweet potato are the main standard field crops grown in Vhembe District. The most methods used for irrigation are drip irrigation and furrow irrigation for those who have access to water. In most of these municipalities, vegetables are rotated with field crops occasionally.

6.2.2. Study approach

Sampling concentrated on smallholder farmers found in rural areas and in peri-urban areas. Hundred and sixty-three farmers were selected randomly from a list of household farmers provided by extension officers. Quantitative data was collected using questionnaires Qualitative data was collected through focus group discussions and key informants. Three focus groups were conducted in each municipality. This consisted of seven women, seven men and a combined group of seven men and seven women. Seven women and seven men were randomly selected from a list of farmers who did not participate in the questionnaire. Key informants selected in each municipality were extension officers and old age farmers familiar with the municipality. A checklist was used to collect qualitative data from key informants and focus group.

6.2.3. Data analysis

The data was encoded in IBM Statistical Package for Social Sciences (SPSS) 23. Chi-square was used to compare the differences between different variables. Means and significant differences between means were declared at $P \leq 0.05$.

6.3. Results

6.3.1. Major issues raised on government

All farmers stated what the government; researchers and extension should improve their agricultural production.

All municipalities in both dryland and irrigated systems highlighted the important issues (Table 6.1) such as:

- Government should supply chemicals and fertilisers
- Government should supply farmers with tractors
- Seeds must be supplied to farmers
- Water must be made available to farmers

More issues were highlighted in irrigated systems whereby farmers mentioned that (Table 6.1):

- Government must train farmers on pest management and prevention

- Farmers must be trained on how to use chemicals
- Government must remove bush encroachment alongside roads to prevent pests from harbouring in bushes

Table 6.1: Issues raised by farmers on what government services they need in order to solve pest management and agricultural constraints

Municipality	Dryland	Irrigated
Mutale	- supply chemical and fertilizers -provide water reservoirs and boreholes -tractors must be provided to plough	-supply chemical and fertilizers to farmers -tractors must be provided for ploughing -transport to markets must be provided -chemical control equipment's such as knapsacks must be supplied to farmers -maintenance of furrows in the irrigation schemes -water must be supplied regularly and farmer challenges must be resolved
Makhado	-supply chemicals for pest control -seeds must be treated with chemicals for drought tolerance	-provide farmers with chemicals and quality fertilizers -must provide seeds -fields must be sprayed by helicopter at least once a month
Thulamela	-supply farmers with chemical and seeds -supply varieties resistant to pest and disease -provide water -agricultural budgets must be monitored	-subsidize fertilizer and pesticides -teach farmers how to prevent insect pest and how to use chemicals -remove bush encroachment -furrows must be maintained
Musina	Dryland farmers in Musina were not interviewed due to logistical interviews.	-provide effective chemicals -biosecurity at borders and airports must be tightened - predictions and early warning of new pests and diseases to farmers -must supply chemicals with different active ingredients for effective control -must check if there are residuals chemicals on produce which can harm human beings - must provide with better facilities and transport to help farmers

6.3.2. Major issues on extension

Results show that in all municipalities the major issues raised by both dryland systems and irrigated systems are as follows:

- Extension officers must visit farmers regularly in their farms (Table 6.2)
- Extension must facilitate tractors offered to plough in farmers' fields during ploughing seasons
- Farmers want extension officers to organise seminars for them in order to learn more on good agricultural services
- Extension must train farmers on marketing procedures
- Chemical control methods must also be taught to farmers

Table 6.2: Issues raised by farmers on how extension services must assist them in their pests management and agricultural production constraints

Municipality	Dryland	Irrigation
Mutale	- visit farmers regularly -teach farmers more skills on farming -tractors must be monitored when ploughing -assist in soil sampling and analysis -must stop applying favoritism -more meetings are needed to discuss these challenges	-visit farmers regularly -run courses for farmers on farming - educate farmers about markets - supervise tractor drivers during ploughing
Makhado	- facilitate tractors to plough -share knowledge on farming with farmers - assist farmers with markets -assist with reservoirs for irrigation	farmers must be taught on climate smart agriculture -teach farmers on how to use chemicals -visit farmers regularly and help them solve problems
Thulamela	-visit farmers regularly to attend their problems -teach farmers about marketing and other agriculture practices	organize workshops for farmers to learn more on agricultural production -visit farmers regularly -young farmers must be trained -bush encroachment must be removed
Musina	Dryland farmers in Musina were not interviewed due to logistical interviews.	-Extension in Musina were very effective -must train farmers on chemical application -source markets for farmers -advisory services to farmers.

6.3.3. Major issues raised on research

Analysis of data from questionnaires, focus group discussions and key informants across municipalities in both dryland and irrigated systems highlighted the following research issues

- Researchers must take results back to farmers after completion of research in farmers' fields.
- More research on pest control, effective of pesticides, development of resistance by pests, impact of chemical residues on vegetables and human health.
- More research on soil fertility
- Research must work with farmers and extension officers on pest control.

- Research on interaction of climate change with pest outbreaks
- Modelling pest outbreaks and distribution

Table 6.3: Issues raised by farmers on how research can assist them in their crop production constraints

Municipality	Dryland	Irrigation
Mutale	-findings must be returned to farmers -more research on soils, pest and diseases -must be educated on pest and diseases -farmers must be linked to markets	- return findings to farmers and extension officers -must have good working relationship with extension officers -must educate farmers about farming
Makhado	-findings must be given to farmers and extension -on drought tolerant crops -more studies on climate change e.g. how to control pests in changing climate -birds which damage crops must be studied and how to control them -mixing fertilizers and manure -more research on soils	-should return findings to farmers -bring effective chemicals -farmers must be taught on climate smart agriculture
Thulamela	-bring finding back to farmers -assist with finding to help farmers -new technologies must be introduced	-return their findings to farmers -teach farmers on new practices -farmers must be taught on pesticides -visit farmers and assist with their problems
Musina	Dryland farmers in Musina were not interviewed due to logistical interviews.	-should be done on irrigation systems which use less water -research on water storage and utilisati0n

6.4. Discussion

This list of research priorities, which were set by farmers, are very different from what researchers are working on in these areas except this project and a few more. Many researchers are not disseminating results after completing their research in the field with farmers. Farmers demanded these results from extension officers and researchers. This research is what is called extractive research whereby researchers are taking information from farmers without giving back the results from farmers.

The model of research used by researchers in this area is called technology supply push (TSP). The TSP model assumes that research provides technologies that boosts yields. Information flow is linking research through extension services and then extension services links with rural farmers and users of the technology. This is a top-down approach to research (Spelstra and Elzen, 2010). However, this model has failed dismally over time. It did not make a dent on the productivity of smallholder farming systems (Spelstra and Elzen, 2010).

There is a need to shift research approaches from top-down to a family of participatory approaches and methods that emphasize on local knowledge and enable local people make their own appraisal and analysis. Two such suggested approaches are famer participatory research (FPR) and participatory technology development (PTD). FPR is an approach, which involves and encourages farmers to engage in experimentation in their own fields so that they can see, look, learn and adopt new technologies and spread them to other farmers (Van de Fliert and Braun, 2002). PTD is a joint experimentation and research by farmers and development agencies in developing ways of improving farmer's livelihoods (Schot, 2001). Both FPR and PTD emphasize farmer's participation. Both methods recognize that:

- Farmers have extensive, well-developed knowledge of their environment, crops, livestock and their practices.
- farmers carry out experiments on their own and generate innovations
- farmers actively exchange information and technologies

In these approaches, farmer priorities for research are articulated by farmers themselves and are relevant to their situation. In PTD, or participatory innovation and development (PID) evolves joint working between farmers, researchers, and other advisory services to analyze problems and opportunities. The approaches identify things to try, trying them out in the community, analyzing and sharing results. It also improves local organizations and linkages with other actors in research and development continuum. Adoption of these methods will go a long way in generating a research agenda, which is relevant to farmer's circumstances, and solve farmer's real problems.

The word extension was derived from the word extend, meaning there is extending of services to farmers from appointed officers to improve human livelihoods (Davis, 2008). The role of extension is to transfer technology, manage agricultural skills through education and training farmers (Davis, 2008). However, in today's era, the role of extension has more major services to be delivered than just assisting farmers to maximize their production. Today extension goes as far as educating farmers on how to market their products and creating partnership with stakeholders (Davis, 2008). According to this study, farmers were clearly pointing out that extension services were not delivered optimally in both irrigation and dryland farming systems. However, it is only in Musina municipality were farmers seemed to be satisfied with extension services.

Lack of transport is the major reason why extension officers cannot visit farmers for service delivery. This challenge has also been reported in other African countries (Ragasa et al., 2016). Transport challenges have limited the mobility of extension officer to farmers, leading to inadequate assistance to farmer's problems. Poor education of extension officers is another challenge to adequate service delivery to farmers. Lack of education of extension officers' resulted in poor problem solving of farmers. Majority of farmers across municipalities indicated that they needed more training to be done on soil fertility, soil sampling, climate change, marketing and how to use chemicals. This indicated that farmers were hungry to learn and to be educated. This suggests that extension officers need to be trained on these issues in order to transfer knowledge to farmers. Farmers indicated that extension officers were hardly found in offices allocated to them in villages. The reason for this might be resulting from lack of office facilities to use, for example, electricity, landline phones and other electrical equipment to use in their offices.

6.4.1. What needs to be done to improve service delivery?

Approaches need to be put to practice for improvement of services.

Extension must use participatory methods to assist farmers with their challenges. These methods can be achieved through farmer's field schools. The role of farmer's field schools is to educate farmers through either teaching or experiments and other participatory methods. Farmers can group themselves in 20 to 25 members. With this method, each group meets on a weekly basis for meetings were they discuss their challenges and how they can solve them.

This method allows farmers to be in charge of themselves. Farmers can conduct experiments on their own and can be able to diagnose problems and how to address them in their farms as a group. This method has produced good results in African countries such as Mozambique, Kenya, Tanzania, Uganda and Zimbabwe (Anandajayasekeram, et. al., 2007) and can be implemented in Limpopo Province farmers.

Challenges that makes government no to be effectively rendering services to farmers includes affordability of inputs needed by farmers. The government fails to access inputs such as fertilizers and chemicals due to high costs or inadequate arrangements for financing the purchase of these inputs (Crawford et al., 2003). This could be the main reason why government is failing to supply inputs to farmers in Limpopo Province in large numbers. According to focus group discussions farmers mentioned that not all farmers received inputs from the government. Some farmers did receive inputs and other farmers did not receive anything at all. Some of these inputs have been expensive due to lack of subsidies (Gordon, 2000). There are other factors, which can also influence high costs of inputs such as low volume imports for farmers and poor roads (Gordon, 2000).

The availability of inputs is also a major factor why government fails to deliver inputs to farmers. Although farmers can be large in number, the purchasing power of these inputs are usually low in African countries, therefore this influences small market purchases of agricultural inputs (Gordon, 2000). Many inputs may not be available for purchasing because the volumes that can be sold are very small.

Profitability of input and output markets is another factor resulting to low availability of input supply. Low profitability affects the purchase of inputs by farmers (Poulton et al., 2006). Farmers believe that lack of profitability is influenced by high input prices and low output prices. This includes transport costs, fertilizer costs, transaction costs, marketing agents (Poulton et al., 2006). Profitability and risks in input is also affected by the quality of inputs and the efficiency in which they are used. The traders must also be able to perceive the effective demand as high enough for them to prompt provision of inputs to farmers.

6.4.2. Strategies to facilitate input supply

Instead of government investing more on resources to provide to farmers, governments must focus on serious deficiencies in Limpopo Province such as irrigation, roads, market information, research and extension and improved institutions such as contract law and enforcement. Improving these aspects can help lower supply costs and increase farm- level demands (Kelly et al., 2003). Competitive, sustainable and viable agricultural input supply via intermediaries in South Africa can be achieved through public-private partnerships (Dorward et al., 1998).

Contract farming plays a crucial role in smallholder farmers in different ways. Credit for agricultural inputs can be sourced through contract farming. This allows contractors to use farmer's expected harvest as a guarantee for seasonal input credit. Costs of inputs can also be reduced if ordered in bulk. Farmers in Mali had reduced input costs when inputs were ordered in bulk (Kelly et al., 2003).

Smart input subsidy programmes can also be efficient in supply of inputs to farmers. Most African countries such as Tanzania, Kenya, Zimbabwe and Malawi have subsidy programs running in their countries (Dorward, 2009). This involves the supply of inputs to farmers at controlled and subsidized process (Baltzer and Hansen, 2011). In many cases, this method can increase input use by farmers and increase agricultural productivity.

Government run input-credit schemes can also be used to solve the issue of input supply. This programme makes credit to be more available to farmers when commercial banks find operational costs too high (Kelly et al., 2003).

6.5. Conclusion

From this study, it was showed that farmers lack support from the government, extension services and researchers. The study also showed that there were many constraints behind poor service delivery to farmers by government, extension and researchers. Smallholder farmers required support for improving their agricultural production. This support comes in the form of input supply, training by government on important aspects of obtaining good agricultural production. This study also shows that farmers in Limpopo Province were not yet well educated in various aspects that could improve their production. There is a need for farmers to be well trained on pest management, marketing processes and other agricultural practices. There is a need for plural systems in extension services, research and government input supply. In extension, pluralism can be achieved by involving many players. These include government extension services, extension services provided by NGOs, contract farming, farmer-to-farmer extension, the private sector and agricultural universities. In government input services, partnership with private sectors, contract farming, farmer credit group associations and credit schemes by banks must be done. Government research must be complemented by university research, private sectors, NGOs and farmers own research experience.

References

Arrow, K.J., & Lind, R.C. (2014). Uncertainty and the evaluation of public investment decisions. *Journal of Natural Resources Policy Research, 6,* 29-44

Anandajayasekeram, P., Davis, K.E., & Workneh, S. (2007). Farmer field Sshools: An alternative to existing extension systems? Experience from Eastern and Southern Africa. *Journal of International Agricultural and Extension Education, 14,* 81-93

Baltzer KT., & Hansen, H. (2011). *Agricultural input subsidies in SubSaharan Africa. Ministry of Foreign Affairs of Denmark.* Danida, pp. 8- 36

Barzman, M.S., Bertschinger, L., Dachbrodt-Saayden, S., Graf, B., Jensen, J.E, Joergensen, L.N., Kudsk, P., Messean, A., Moonen, A., Ratnadass, A., Sarah, J.L., & Sattin, M. (2014). *Integrated pest management policy, research and implementation, European initiative*. In: Peshin, R, Pimentel, D, (eds) Integrated pest management. Springer Dordredt

Birner, R., K. Davis, J. Pender, E. Nkonya, P. Anandajayasekeram, J. Ekboir, A. Mbabu et al. 2009. "From Best Practice to Best Fit: A framework for designing and analyzing pluralistic agricultural advisory services worldwide." *Journal of Agricultural Education and Extension, 15,* 341-355

Brournels, M. (2014). *The local government handbook of South Africa 2014: a complete guide to municipalities in South Africa, 4th edition*. Yes! Media, Calermount, RSA, Pp. 2015

Chowa, C., Garforth, C., & Cardey, S. (2013). Farmers experience of pluralistic agricultural extension, Malawi. *The Journal of Agricultural Education and Extension, 19,* 147-166

Crawford, E.W., Jayne, T.S., & Kelly, V.A. (2006). *Alternative Approaches for Promoting Fertilizer Use in Africa*. Agriculture and Rural Development Discussion Paper 22. Washington D.C: The World Bank

Davis, K. (2008). "Extension in Sub-Saharan Africa: Overview and assessment of past and current models, and future prospects." *Journal of International Agricultural Education and Extension 15,* 15–28

Dorward, A. (2009). *Rethinking Agricultural Input Subsidy Programmes in a Changing World.* London: School of Oriental and African Studies

Dorward, A., Kydd, J., & Poulton, C. (Eds). 1998. *Smallholder Cash Crop Production under Market Liberalisation*. CAB International, Oxford and New York

Evenson, R.E. (2001). Economic impacts of agricultural research and extension. *Handbook of Agricultural Economics, 1,* 573-628

Gordon, A. (2000). *Improving Small-Holder Access to Purchased Inputs in Sub-Saharan Africa.* Policy Series No 7.Natural Resources Institute, Chatham, UK

HLPE. (2012). Social protection for food security. A report by the high level panel of experts on food security and nutrition of the committee on word food security, Rome, 2012

IAASTD. (2009). Agriculture at cross roads: the synthesis report. Wasington DC. USA: international assessment of agricultural knowledge, science and technology for development. www.assessment.org

Kelly, V., Adesina, A.A., & Gordon, A. (2003). Expanding access to agricultural inputs in Africa: A review of recent market development experience. *Food Policy, 28,* 379-404

Magoro, M.D., & Hlungwani, S.S. (2014). The role of agricultural extension in the 21 century: Reflections from Africa. *International Journal of Agricultural Extension, 20,* 89-93

Marsh, S.P., & Pannell, D.J. (2000). Agricultural extension policy in Australia: the good, the bad and the misguided. *The Australian Journal of Agricultural and Resource Economics, 44,* 605-627

Mpandeli, S.N. (2006). Coping with climate variability in Limpopo province. Unpublished PhD thesis, University of Witwatersrand lessons from southern Africa. *South African Journal of Science, 105,* 34-49

Phophi, M.M., & Mafongoya, P.L. (2017). Constraints to vegetable production resulting from pest and diseases induced by climate change and globalization: a review. *Journal of Agricultural Science, 9,* 11-25

Poncet, J., Kuper, M., & Chiche, J. (2010). Wandering off the paths of planned innovation: the role of formal and informal intermediaries in a large-scale irrigation scheme in Morocco. *Agricultural Systems, 103,* 171-179

Poulton, C., Kydd, J., & Dorward, A. (2006). Overcoming market constraints on pro-poor agricultural growth in sub-Saharan Africa. *Development Policy Review, 24,* 243-277

Poulton, C., Dorward, A. & Kydd, J. (2010). The future of small farms: New directions for services, institutions, and intermediation. *World Development, 38,* 1413-1428

Ragasa, C., Ulimwengu, J., Randriamamonnjy, J., & Badibanga, T. (2016). Factors affecting performance of agricultural extension: evidence from Democratic Republic of Congo. *The Journal of Agricultural Education and Extension, 22,* 113-143

Schot, J. (2001). Towards new forms of participatory technology development. *Technology Analysis and Strategic Management, 13,* 39-52

Spoelstra, S., & Elzen, B. (2010). *Combining top-down and bottom- up approaches towards sustainable livestock production. A learning and experimentation strategy (LES)*. In: Emile, L, Devautour, H., Soulard, T.C., Hubert, B. ISDA, 2010. Montepillier, France. Cirad-Inva-Supagio, Pp 12

Stats SA (2011). Census 2011: Provincial profile: Limpopo/ Statistics South Africa. http://www.Stats Sa.gov.za/publications/report-03-01-78/report-03-01-782011

Van de Fliert, E., & Braun, A.R. (2002). Conceptualizing integrative, farmer participatory research for sustainable agriculture: From opportunities to impact. *Agriculture and Human Values, 19,* 25-35

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1. Research findings

Vegetables are essential for food security and human nutrition. They have nutrients such as vitamin A, E, C, zinc and other minerals such as calcium, potassium and phosphorus. Major constraints to vegetable production are pests such as insects, weeds and diseases. Insect pests account for 16% of crop yield loss. Climatic changes have the potential to influence pest population, distribution, migration, and multiple pest generation. Very few studies have been conducted in Limpopo Province on climate change and its impacts on insect pests. This study focused on new and emerging pests of vegetables under climate change in four municipalities namely: Mutale, Makhado, Musina and Thulamela, of Vhembe District, Limpopo Province in South Africa. The study was conducted to determine farmer's perceptions on climate change, knowledge on insect pests, symptoms caused by insect pests and the behavior of these insect pests. The study also focused on the new and emerging insect pests and the control measures taken by farmers to control pests as well as the role of institutions in pest management in Limpopo Province.

The findings of this study revealed that major crops in this province were maize, sweet potato, tomatoes, cabbage, black nightshade and mustard spinach. Results show that famers were aware of climate change and the indicators of climate change. Majority of farmers indicated that long dry spells, increased drought frequency, late rainfall and warmer winters were some of climate change indicators they have observed. Farmers indicated that from the last decade, temperatures and drought have shown to increase and rainfall patterns seem to be fluctuating in Limpopo Province.

Farmers were able to identify problematic insect pests and amongst the mentioned, the major problematic pests in maize were fall armyworm, armoured bush cricket, and stalk borer. In vegetables, problematic pests were aphids, red spider mites, diamond back moths, bagrada bugs and cutworms. This means that farmers were aware of the minor and major pests in their crop production system. The study showed that bagrada bug and armoured bush cricket were emerging insect pests in the Limpopo Province. Bagrada bug was more abundant in Thulamela dryland system and least prevalent in Mutale irrigated system. Armoured bush cricket was more abundant in Musina municipality and least prevalent in Mutale irrigated system. These pests were regarded as minor pests in the previous years. However, their damage incidence on vegetables were observed to have increased. Aphids were more prevalent in cabbages, tomatoes, and black nightshade in all municipalities. Diamondback moth was also prevalent in all municipalities and was problematic to cabbages. With respect to new pests, fall armyworm (*Spodoptera fruigiperda*) and tomato leaf miner (*Tuta absoluta*) were observed as new insect pest in Limpopo Province. Farmers first saw fall armyworm in early summer months of 2017 and *Tuta absoluta* was first detected in 2016. These pests have shown to adapt to the climatic conditions and environments of Limpopo Province. Farmers have observed the level of damage caused by these new insect pests. The damage was said to be extensive on maize and tomatoes respectively. Farmers also mentioned that some chemicals they used were not effective enough for managing these new insect pests. This was because these pests were invasive and therefore effective chemicals for these pests were not yet locally recommended pesticides in the country. However, the government has tried to supply recommended chemicals for managing these pests, which are effective if applied correctly and at the right dosage.

Farmers in all municipalities practice chemical control to manage insect pests. This was the most practiced method compared to other pest control measures. Farmers indicated that chemicals were effective for pest management in vegetables and field crops. The reason why farmers were not practicing other methods was that they lacked knowledge and training from government, NGOs and other private sectors. Cypermethrin was the most used chemical for insect pest control across all municipalities. One of the toxic chemical used by farmers was Methamidophos. Farmers were not aware that this chemical is very harmful. WHO rank it under the highly toxic chemical. With improper chemical application methods, this chemical is most likely to affect human health and lead to environmental degradation.

With respect to role of institutions, farmers mentioned that extension workers were failing to provide advisory services to farmers. The reason why extension was failing included poor transport facilities, lack of knowledge and lack of funds. Results indicated that farmers were not well trained on many aspects such as pest control, marketing of products, soil fertility and breeding. Farmers indicated that the government must train them on good agricultural practices. Research must always return findings to farmers. Farmers also mentioned that more research must be done on soil fertility, drought resistance crops, soil organic matter, inorganic fertilizers and manure application.

7.2. Implications

This study implied that insect pests were more prevalent in Limpopo Province due to climatic factors such as increased temperatures, drought spells and erratic rainfall. Climatic conditions have influenced the increase in pest populations, mobility and fast reproduction. New pests were suspected to have arrived due to trade, people's movement and poor phytosanitary measures at country borders. Emerging pests such as bagrada bug and armoured bush cricket became major insect pests due to climatic factors. These pests are still expected to be problematic in the future. Poor pest control was also involved in increased pest prevalence and pest resistance development in Limpopo Province.

Due to increased prevalence, farmers will increase the use of chemicals to manage pests. According to focus group discussions, farmers aimed at eradicating these pests through increasing application frequency of pesticides. This will lead to high levels of pesticide resistance if application frequencies are not reduced. This will also increase the pesticide residue on crops and increase environmental contamination.

This study also revealed that farmers were vulnerable to climate change and its influence on increased pest infestations. Majority of the insect pests survive in higher temperatures of more than 27 ^{o}C. Due to high temperatures in Limpopo Province, farmers are most likely to experience more pest damage on their crops, especially those who grow same crops throughout the whole year. Farmers are not well trained on how to adapt and mitigate to climate change and all the changes on pests resulting from climactic factors. This is because there are poor extension services from extension workers, NGOs and lack of researchers and research conducted on this issue.

7.3. Recommendations

Farmers must be trained more on pest management practices such as cultural control, mechanical control, biological control and integrated pest management. These will reduce the chances of pesticide resistance build up, contamination to the environment and harm to human health, and to reduce levels of pesticide residues on vegetables. The service delivery to farmers by extension will enlighten farmers on what measures to practice on their farms. Research needs to assist farmers by returning their findings and training farmers on new methods of sustainable agriculture production and climate smart agriculture.

Government must improve phytosanitary measures at border and airports (entry and exit points). This will assist in preventing entry of invasive pests from other countries. Biosecurity measures on farms must be monitored extensively to prevent spread of insect pests' attack. This will enhance food security and reduce crop loss resulting from insect pests. This will also reduce loss of money used by the government in eradicating pest problems. Government must work with extension to raise awareness to farmers on new insect pests' threats in the country. This will help the government and farmers to prepare for prevention of pest entry and spread into the country.

There is need for farmers to be well trained on how to apply pesticides and what precautions they need to follow during pesticide application. Farmers must be well trained on types of chemicals and the danger they can impose on human health, environment and natural enemies. More training is needed on pesticide rotation to increase efficiency and to reduce resistance build up. Researchers must conduct modelling of pests using pest risk maps in order to predict the spread of pests and the areas expected to be vulnerable to pests. This information will also help farmers in preparation of pest management using various methods of pest control.

7.4. Future research needs

- Some research must be done on the biology of new insect pests in South Africa (*Tuta absoluta* and *Spodoptera frugiperda*). Little is known on the biology of these insect pests and how they are adapting in Limpopo Province's climatic conditions.
- More research must be conducted on the natural enemies of problematic insect pests in Limpopo Province, in order to manage insect pests. This should be done in order to reduce the level of pesticide application and to avoid build-up of pesticide resistance.
- Research must be conducted on pesticide residues on vegetables. Consumption of vegetables with high rates of pesticide residues will lead to chronic diseases in humans.
- Studies must be conducted on the link of insect pests and climate change. The influence of climate change on insect pests need to be well understood by both extension personnel and farmers in order to find strategies of adaptation and how they can mitigate the problem of insect pests.

- Future research must be done on the impact of pesticide residues and human health and environment. This must be done to prevent problems in human health, to prevent and reduce environmental degradation and to conserve soil microorganisms.
- Developing methods of reducing pest resistances development. Reduction of pesticide resistance can be achieved through using companion crops to manage pests and cultural methods. Rotation of chemicals with different modes of action must also be made aware to farmers who do not have knowledge about it.
- Moving research from top-down to participatory approaches, which will involve farmers on problem identification, experimentation, monitoring and evaluation. This will make research address real farmers' problems.

Appendix

A. **SURVEY QUESTIONNAIRE**

My name is Mutondwa Masindi Phophi and I am a PhD student working on a research topic entitled "Impacts of climate change and variability on Aphids and other emerging pests in South Africa". I am kindly asking for your ideas, opinions and information pertaining to the various ways in which the insect pests are responding to a changing climate in South Africa. May you kindly assist freely with your views and comments? All the information collected here will be treated with strict confidentiality as it is only for the purpose of academic research.

Instructions: Please tick √ where applicable and fill in where there are spaces

1. Gender of the respondent: Male ☐ Female ☐
2. In which natural region are you? Mutale ☐ Thulamela ☐ Makhado ☐ Musina ☐
3. Are you aware of a changing climate in South Africa? Yes ☐ No ☐
4. What are the indicators of a changing climate in your district?
   1. Late rainfall
   2. Long dry spells
   3. Erratic rainfall
   4. Shortened rainy season
   5. Increased frequency of droughts
   6. Shortened cold season
   7. Increased frequency of floods
   8. Other specify____
5. (a). Which insects are most problematic in your natural region?
   1. Bollworms
   2. Aphids
   3. Cutworms
   4. Armyworms
   5. Red spider mite
   6. Beetles
   7. Whitefly
   8. Diamond moth
   9. Other Specify____

5 (b). Can you rank the above listed insect pests in order of importance (Most important to least importance?)

1. ____
2. ____
3. ____
____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10. ____

6. How do you view the problem of insect pests in your natural region for the past 30 years?
   1. It has increased
   2. It has decreased
   3. There is no change

7. Which field crops are mostly attacked by these insect pests?
   1. Maize
   2. Tobacco
   3. Sorghum
   4. Sweet potato
   5. Other specify____

8. Which vegetable crops are most attacked by insect pests?
   1. Sugar beans
   2. Green beans
   3. Tomato
   4. Garlic
   5. Onion
   6. Pepper
   7. Cabbages
   8. Spinach
   9. Others specify____

9. When the crops mentioned in question 7 & 8 are not available in the field, which alternative crops are attacked by these insects?

Crop	**Alternative crops**
Maize	
Tobacco	
Sweet potato	
Tomatoes	
Sorghum	
Spinach	
Sugar beans	
Green beans	
Garlic	
Onion	
Pepper	
Cabbage	
Other specify	

10. Besides alternative plants, name the weeds or plants that act as alternative hosts of these insect pests?

Crop	**Alternative weeds**
Maize	
Tobacco	
Sweet potato	
Sorghum	

vegetables	

11. In which season are these weeds most dominant? Summer ☐ Autumn ☐

Winter ☐ Spring ☐ .All year round ☐

12. Is there a change in the population of the insect pests over the last 30 years?
13. There is an increase ☐ There is a decrease ☐ There is no change ☐

14. If there is an increase in number of insect pests, what factors do you think have led to increased incidence of these insect pests?
    1. Shortened winters
    2. Warmer winters
    3. Increased dry spells
    4. Insect pests resistance
    5. Poor insect pest management
    6. Low rainfall
    7. Other Specify____

15. Which season of the year are these insect pests most prevalent?

Summer ☐ Autumn ☐ Winter ☐ Spring ☐

All Year round ☐

Insect pests' biology, physiology

16. How do you perceive the problem of insect pests with respect to the following attributes in the past 10-30 years:

Behaviour:
1. They have increased mobility
2. They are generating young ones very fast
3. Many pests are now flying
4. They are becoming too crowded even on older leaves
5. They are producing too many eggs

Physical appearance:
1. They have developed different colour variations
2. They have generally become lighter in colour
3. They have generally become darker in colour
4. Many of the pests have developed wings

Symptoms they cause:
1. Yellowing of the whole leaves
2. Mottling-green mixed with yellow and white colour
3. Stunted growth-slow growth
4. Blackening of leaf veins
5. Asymmetry of leaf lamina
6. Brown spots
7. Leaf roll
8. Line pattern on the leaves

17. Which measures do you use to control the problematic insects?
    1. Biological
    2. Chemical
    3. Mechanical
    4. Cultural control
    5. Integrated Pest Management (IPM)
    6. Other Specify___________________________________

18. If you are using chemical insecticides which chemicals do you use and on which crops?

Crops	**Chemical Insecticide used**
Maize	
Tobacco	
Sweet potato	
Tomatoes	
Sorghum	
vegetables	
Other specify	

19. Are the chemical insecticides effective in the control of the insect pests?
   1. Yes ☐ 2. No ☐

20. Give reasons to your answer on question 18

____

____

____

____

____

21. How frequent do you spray these chemical insecticides?
   1. Once/month ☐ 2. Once /week ☐ 3.Twice/week ☐ 4.Three times/week ☐

   5. Other, please specify_____________________________________

22. Is there a difference in spraying frequency from what you used to do in the past years?
   1. Yes ☐ 2. No ☐

   If yes/No why? ____

   ____

   ____

   ____

   ____

23. Do you rotate these chemical insecticides? 1. Yes ☐ 2. No ☐

   If No why?

   ____

   ____

   ____

   ____

   ____

   If Yes Why?

   1. To increase efficiency
   2. There are no other alternatives in the area
   3. They are cheap
   4. They control crops in a wide range of crops
   5. Other___________________________________

24. Giving names, explain the role played by named natural enemies in the control of the insect pests
    1. Ladybirds
    2. Lacewings
    3. Spiders
    4. Big eyed bugs
    5. Parasitic flies
25. Are these natural enemies effective or their efficiency has been reduced over the past years?

    Yes ☐ No ☐

26. If No, what do you think could be the reason for a reduction in efficiency of the natural enemies?

    1. They are becoming fewer
    2. They can't feed on the big insects
    3. They have developed many hosts
    4. Natural enemies are overwhelmed by aphid population
27. Aphids have become a problem in all crop growing areas of the country. What do you think?

    1. Strongly agree ☐ 2. Agree ☐ 3.Neutral ☐ 4. Disagree ☐

    5. Strongly disagree ☐

28. If aphids are an important insect pest, in which crops are the aphids most prevalent?

Field Crops
Sorghum
Maize
Sweet potato
Tobacco
Horticultural Crops
Tomatoes
Onions
Cabbages
Spinach
Sugar beans
Green beans
Pepper
Garlic
Other specify

29. What corresponding diseases or symptoms are caused by these aphids?
    1. Yellowing
    2. Mottling/mosaic symptoms
    3. Brown spots
    4. Stunted growth
    5. Curling upwards
    6. Curling downwards
    7. Death of plants

30. Can you comment on the responses of aphids to a changing climate in South Africa

    Behaviour:

1. They have increased mobility
2. They are generating young ones very fast
3. Many pests are now flying
4. They are becoming too crowded even on older leaves
5. They are producing too many eggs

Physical appearance:
1. They have developed different colour variations
2. They have generally become lighter in colour
3. They have generally become darker in colour
4. Many of the pests have developed wings

Symptoms they cause: 1.Yellowing of the whole leaves
2. Mottling-green mixed with yellow and white colour
3. Stunted growth-slow growth
4. Blackening of leaf veins
5. Asymmetry of leaf lamina
6. Brown spots
7. Leaf roll
8. Line pattern on the leaves

31. Do you have any question you want to ask about pest and climate change in general

B. Checklist for focus group and key informants

1. What are the key vegetable crops that are grown in this area? Rank in order of importance
2. What are the main pests observed in order of importance
3. What are the key pest on each vegetable in order of importance?
4. What do you think are the major causes of these pests?
5. What do you do to control these pests
6. Which method is effective and why?
7. What should be done by the:
    - Government
    - Extension
    - Research

Any other suggestion