2020-06

Effectiveness of pesticidal plant extracts on field and post-harvest pests in Bambara groundnuts in Tanzania

Tlankka, Nicodemus Sakweli

NM-AIST

https://doi.org/10.58694/20.500.12479/1021

Provided with love from The Nelson Mandela African Institution of Science and Technology
EFFECTIVENESS OF PESTICIDAL PLANT EXTRACTS ON FIELD AND POST-HARVEST PESTS IN BAMBARA GROUNDNUTS IN TANZANIA

Nicodemus Sakweli Tlankka

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master’s in Life Sciences of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

June, 2020
ABSTRACT

A randomized complete block design (RCBD) experiment was conducted to assess the effectiveness of Bidens pilosa, Lantana camara, Vernonia amygdalina, Tithonia diversifolia, Tephrosia vogelii and Lippia javanica against field pests of bambara groundnuts. The extracts were prepared by dissolving powder of the plants leaves at the concentration of 10% (w/v) in tap water containing 1% soap and left for 24 hours. Then, extracts were sprayed on 2 weeks seedlings of bambara groundnut and assessment of the abundance of insect pests and beneficial arthropods and plant damage was conducted weekly for 15 weeks. The results showed that pesticidal plants significantly ($P \leq 0.05$) reduced the abundance of foliage beetles, aphids, mealybugs, red spider mites, and leafhoppers and caused significantly ($P \leq 0.05$) less threat to ladybird, hoverfly, wasps and spiders. A storage experiment was conducted to assess the insecticidal effectiveness of B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica, T. diversifolia and Croton dichogamus leaves powder on Callosobruchus maculatus. The pesticidal plants powder were admixed with grains at the dosage of 10% (w/w) and compared with actellic dust and untreated control. The experiment was monitored for 6 months. T. vogelii and actellic dust were the most effective treatments by killing 93.07 - 100% and 91.33 - 100% of bruchids respectively for 180 days of the study. Therefore, Tephrosia vogelii is recommended in controlling field and post-harvest pests in bambara groundnuts. Further research is recommended to assess the active compounds, mode of action and toxicity of T. vogelii and assess its effect on non-target organisms in bambara groundnuts.
DECLARATION

I, Nicodemus Sakweli Tlankka, do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

__________________________                                        _____________________
Nicodemus S. Tlankka                  Date
Name and signature of candidate

The above declaration is confirmed;

__________________________                                            _____________________
Prof. Patrick A. Ndakidemi                  Date
Name and signature of supervisor

__________________________                                            _____________________
Prof. Steven Belmain                  Date
Name and signature of supervisor

__________________________                                            _____________________
Dr. Ernest R. Mbega                  Date
Name and signature of supervisor
COPYRIGHT

This dissertation is copyright material protected under the Berne Convention, the Copyright Act of 1999 and other international and national enactments, in that behalf, on intellectual property. It must not be reproduced by any means, in full or in part, except for short extracts in fair dealing; for researcher private study, critical scholarly review or disclosure with an acknowledgment, without a written permission of the Deputy Vice Chancellor for Academic, Research and innovation, on behalf of both the author and the Nelson Mandela African Institution of Science and Technology (NM-AIST).
CERTIFICATION

The undersigned certify that they have read the dissertation titled “Effectiveness of Pesticidal Plant Extracts on Field and Post-Harvest Pests in Bambara Groundnuts in Tanzania” and recommend for examination in the fulfillment of the requirements for the degree of Masters in Life Sciences with specialization in Sustainable Agriculture of the Nelson Mandela African Institution of Science and Technology.

__________________________  __________________
Prof. Patrick A. Ndakidemi  
Name and signature of supervisor  

Prof. Steven Belmain  
Name and signature of supervisor  

Dr. Ernest R. Mbega  
Name and signature of supervisor  

Date

11-06-2020

Date

11-06-2020

Date

11-06-2020
ACKNOWLEDGEMENT

Thanks to God, the Almighty for His guidance and protection throughout my studies. Sincerely, I would like to thank the Nelson Mandela African Institution of Science and Technology for rendering me admission, the Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutrition Security (CREATEES, FNS) for sponsoring my studies. Thanks to the McKnight Foundation for additional funding for my research through the grant from Bill and Melinda Gates Foundation given to The Nelson Mandela African Institution of Science and Technology.

I would like to give many thanks to my supervisors Prof. Patrick A. Ndakidemi, Dr. Ernest R. Mbega (NM-ASIT) and Prof. Steven Belmain (the Natural Resource Institute, University of Greenwich) for their tireless guidance, advice and support to me towards a successful completion of my research work.

Lastly, I would like to express regards to my parents and the entire family members for the prayers, love, encouragement and support that made me complete my studies successfully.
DEDICATION

This dissertation is dedicated to my lovely kids Goodluck and Kendrick and whole family for their love, support, encouragement and prayers that made me perform my studies. It is my prayers that the Almighty God grants you many years of success as you grow up.
TABLE OF CONTENTS

ABSTRACT ................................................................................................................i
DECLARATION ........................................................................................................ii
COPYRIGHT ............................................................................................................iii
CERTIFICATION ......................................................................................................iv
ACKNOWLEDGEMENT ............................................................................................v
DEDICATION .............................................................................................................vi
TABLE OF CONTENTS ..........................................................................................vii
LIST OF TABLES ....................................................................................................xi
LIST OF FIGURES ..................................................................................................xii
LIST OF PLATES ....................................................................................................xiii
LIST OF APPENDICES ............................................................................................xiv
ABBREVIATIONS AND SYMBOLS ..........................................................................xv
CHAPTER ONE ........................................................................................................1
INTRODUCTION .......................................................................................................1
  1.1 Background of the problem .............................................................................1
  1.2 Statement of the problem ...............................................................................2
  1.3 Rationale of the study ...................................................................................3
  1.4 Objectives of the study ..................................................................................3
    1.4.1 General objective ...................................................................................3
    1.4.2 Specific objectives ..................................................................................3
  1.5 Research questions ........................................................................................4
  1.6 Significance of the study ...............................................................................4
  1.7 Delineation of the study ................................................................................4
CHAPTER TWO ..........................................................................................................5
LITERATURE REVIEW ..............................................................................................5
  2.1 Key arthropod pests affecting bambara groundnuts ......................................5
2.1.1 Aphids (Aphis spp.) ................................................................. 5
2.1.2 Groundnut leafhopper (Hilda patrueils Stal) ......................... 6
2.1.3 Foliage beetles (Ootheca mutabilis, O. bennigseni) .................. 7
2.1.4 Groundnut jassids (Empoasca fascilis) ................................ 7
2.1.5 Pod sucking bugs (Clavigralla tomentosicollis Stål) ............... 8
2.1.6 Red spider mites (Tetranychus sp.) ........................................ 8
2.1.7 Bruchids, Callosobruchus maculatus (F.) and Callosobruchus subinnotatus (Pic) ................................................................. 9

2.2 Prospects of pesticidal plants in bambara groundnut arthropod pest control in the field and storage ................................................................. 10

2.2.1 The chemical and insecticidal potential of Croton dichogamus .......... 12
2.2.2 The chemical and insecticidal potential of Tithonia diversifolia .......... 13
2.2.3 The chemical and insecticidal potential of Lantana camara ............. 17
2.2.4 The chemical and insecticidal potential of Bidens pilosa ............... 18
2.2.5 The chemical and insecticidal potential of Tephrosia vogelii .......... 20
2.2.6 The chemical and insecticidal potential of Vernonia amygdalina .......... 22
2.2.7 The chemical and insecticidal potential of Lippia javanica .......... 24

CHAPTER THREE ............................................................................ 27

MATERIALS AND METHODS .............................................................. 27

3.1 Study location ............................................................................ 27
3.2 Pesticidal plant extracts preparation ........................................... 27
3.3 Experimental design and treatments for the field experiment ............ 27
3.4 Data collection ........................................................................... 28

3.4.1 Evaluation of the effectiveness of crude extracts of selected pesticidal plants on the management of bambara groundnuts pests under field conditions and their effects on beneficial arthropods ........................................... 28

3.4.2 Assessment of incidences and severity of different arthropods damage on bambara groundnuts ......................................................... 28
3.4.3 Evaluation of the effectiveness of the application of pesticidal plant crude extracts on yield and yield components of bambara groundnut

3.5 Evaluation of the effectiveness of powder of selected pesticidal plants on managing bruchids on bambara groundnuts

3.5.1 Collection and preparation of plant materials

3.5.2 Collection and rearing bruchids

3.5.3 The experimental setup

3.5.4 Data collection

3.5.5 Data analysis

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Abundance of arthropod pests on bambara groundnut plants

4.1.2 Abundance of beneficial arthropods

4.1.3 Incidences and damage severity of different in arthropods damage on bambara groundnuts

4.1.4 Yield and yield components of bambara groundnut

4.1.5 Live \textit{C. maculatus} on bambara groundnuts

4.1.6 Mortality of \textit{C. maculatus}

4.1.7 Bambara groundnut grains damage by \textit{C. maculatus}

4.1.8 Oviposition of \textit{C. maculatus} on bambara groundnut seeds

4.2 Discussion

4.2.1 Effectiveness of pesticidal plant extracts on field pests in bambara groundnuts

4.2.2 Effectiveness of selected pesticidal plant leaf powders on the management of bruchids (\textit{C. maculatus}) on bambara groundnuts

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS
5.1 Conclusion ........................................................................................................... 52
5.2 Recommendations .............................................................................................. 52
REFERENCES ............................................................................................................. 54
APPENDICES ........................................................................................................... 69
RESEARCH OUTPUTS ............................................................................................... 75
  Output 1: Research manuscript ............................................................................. 75
  Output 2: Review paper ......................................................................................... 75
  Output 3: Poster presentation ................................................................................. 76
LIST OF TABLES

Table 1: Common pesticidal plants found in Africa......................................................... 11
Table 2: Mean number of live insects (C. maculatus) in stored bambara groundnuts....... 39
Table 3: Mean number of dead insects (C. maculatus) in stored bambara groundnuts .... 41
Table 4: Mean number of damaged bambara groundnut seeds ...................................... 43
Table 5: Mean number of bambara groundnut seeds with eggs on the surface............... 45
LIST OF FIGURES

Figure 1: Chemical structure of crotodichogamoin A and B from C. dichogamus roots . 13

Figure 2: Chemical structure of sesquiterpene lactones tagitin A, tagitin B, taginin C taginin F and taginin 2 alpha-hydroxytirotundin, taginins A isomer and dehydrated taginins A . ................................................................. 16

Figure 3: Chemical structures of Lantadene (Pentacyclic triterpenoids) .................. 18

Figure 4: Sesquiterpenes germacrene-D and (b) β-caryophyllene from B. pilosa......... 20

Figure 5: 1-5; T. vogelii Chemotype compounds and 6; T. vogelii Chemotype 2 .......... 22

Figure 6: Structure of compounds isolated from V. amygdalina .............................. 24

Figure 7: Chemical structure of camphor ............................................................. 26

Figure 8: Abundance of key arthropod pests on bambara groundnut plants............ 32

Figure 9: Abundance of beneficial arthropods..................................................... 33

Figure 10: Percentage of bambara groundnut plants infested by key pest species........ 34

Figure 11: Bambara groundnut plants damage by key pests. ................................. 35

Figure 12: Bambara groundnut pod yield (kg ha⁻¹)............................................. 37

Figure 13: Percent corrected mortality of C. maculatus ...................................... 40
| Plate 1: | The picture of *C. dichogamus*, a pesticidal plant. ........................................ 12 |
| Plate 2: | The picture of *T. diversifolia*, a pesticidal plant............................................... 15 |
| Plate 3: | The picture of *L. camara*, a pesticidal plant..................................................... 17 |
| Plate 4: | The picture of *B. pilosa*, a pesticidal plant....................................................... 19 |
| Plate 5: | The picture of *T. vogelii* a pesticidal plant....................................................... 21 |
| Plate 6: | The picture of *V. amygdalina*, a pesticidal plant................................................ 23 |
| Plate 7: | The picture of *L. javanica*, a pesticidal plant.................................................... 25 |
| Plate 9: | Bambara plant damaged by aphids................................................................. 36 |
| Plate 10: | Bambara groundnut plant damaged by red spider mites............................................ 36 |
LIST OF APPENDICES

Appendix 1: Plot layout in RCBD ................................................................. 69
Appendix 2: Arthropod pest abundance ....................................................... 70
Appendix 3: Beneficial arthropods abundance ............................................ 71
Appendix 4: Pests incidence (%) ................................................................. 72
Appendix 5: Plant damage .................................................................... 73
Appendix 6: Yield and yield components of bambara groundnuts ............... 74
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>≤</td>
<td>Less or equal</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees centigrade</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>CREATEs, FNS</td>
<td>Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutrition Security</td>
</tr>
<tr>
<td>DAFF</td>
<td>Department of Agriculture, Fisheries and Forestry</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
</tr>
<tr>
<td>Ha</td>
<td>Hectare</td>
</tr>
<tr>
<td>KG</td>
<td>Kilogram</td>
</tr>
<tr>
<td>LSD</td>
<td>Least Significance Difference</td>
</tr>
<tr>
<td>M</td>
<td>Meter</td>
</tr>
<tr>
<td>MR</td>
<td>Mortality rate</td>
</tr>
<tr>
<td>NARI</td>
<td>Naliendele Research Institute</td>
</tr>
<tr>
<td>NM-AIST</td>
<td>Nelson Mandela African Institution of Science and Technology</td>
</tr>
<tr>
<td>P</td>
<td>Probability</td>
</tr>
<tr>
<td>RCBD</td>
<td>Randomized Complete Block Design</td>
</tr>
<tr>
<td>RH</td>
<td>Relative humidity</td>
</tr>
<tr>
<td>SE</td>
<td>Standard error</td>
</tr>
<tr>
<td>TARI</td>
<td>Tanzania Agricultural Research Institute</td>
</tr>
<tr>
<td>TPRI</td>
<td>Tropical Pesticides Research Institute</td>
</tr>
</tbody>
</table>
CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an important leguminous crop indigenous in Africa (Atiku et al., 2004; Mpotokwane et al., 2008). In many parts of Africa, bambara is ranked the third after peanut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) in terms of consumption and socio-economic importance (Azam et al., 2001; Massawe et al., 2005; Temegne et al., 2018). The grains of bambara groundnuts are highly nutritious containing approximately 15 - 25% protein, 49 - 63.5% carbohydrate, 4.5 - 7.4% fat, 5.2 - 6.4% fiber and 2% mineral (Halimi et al., 2018; Murevanhema & Jideani, 2013). Bambara groundnut is mainly produced for consumption and it serves as a food security crop, eaten as freshly cooked pods or as dry grains combined with main dishes such as cooked plantains and cereals (Heller et al., 1997). Bambara groundnuts serve as a source of income among smallholder farmers especially when the yields of other crops are low due to the prevailing drought and extreme temperatures and crop residues are used to feed livestock (Hillocks et al., 2012; Mayes et al., 2019; William et al., 2016). Being are highly tolerant to tolerant drought and high temperature, bambara groundnut has become a suitable crop for marginal lands (Adeleke et al., 2018; Baryeh, 2001; Hillocks et al., 2012; Mubaiwa et al., 2018; Temegne et al., 2018). Moreover, being a leguminous crop, bambara groundnuts have the ability to fix soil nitrogen of about 20-100 kg ha\(^{-1}\) to the soil useful in crop rotations and intercropping with non-nitrogen fixing crops (Hillocks et al., 2012). Although bambara groundnut has remained underutilized and under-researched for so long (Hillocks et al., 2012) currently, it has attracted research attention and cultivation by farmers mainly due to its climate resilience, unlike other legumes that are at risk due to climate change effects (Mayes et al., 2019; Mkandawire, 2007).

The world production of bambara groundnut in 2016 was estimated by FAO to be 164,589 tonnes whereby the main production is from African countries such as Mali, Cameroon, Niger, Burkina Faso and Democratic Republic of Congo (DRC) (FAO, 2018). In Tanzania, bambara groundnuts are cultivated in Kagera, Mara, Mwanza, Shinyanga, Tabora, Singida, Dodoma, Rukwa, Iringa, Lindi, Ruvuma and Mtwara regions (Heller et al., 1997). However, in Tanzania, the yield of bambara groundnut is 500 - 800 kg ha\(^{-1}\) which is lower than the
potential yield of 1 500 – 2 000 kg ha	extsuperscript{-1} under proper crop management (NARI, 2015). Low production of bambara in Tanzania is attributed by many factors one of which is attack by insect pests such as aphids (*Aphids sp.*), leafhoppers (*Hilda patruleia*), foliage beetles (*Ootheca mutabilis*), groundnut jassid (*Empoasca facialis*) (DAFF, 2016), red spider mites (*Tetranychus sp.*) (Collinson et al., 1996), pod sucking bugs (*Clavigralla tomentosicollis Stäl*) (Dike, 1997) and bruchids (*Callosobruchus maculatus* and *C. subinnotatus*) (Mkandawire, 2007).

In an attempt to control pests in the crops, smallholder farmers apply synthetic pesticides as the major insect pests control strategy (Cooper & Dobson, 2007; Weinberger & Srinivasan, 2009). Although the synthetic insecticide has always provided effective control of insect pests, their use are associated with detrimental effects on the health of the pesticide applicators, consumers and is not environmental benign (Aktar et al., 2009; Bag, 2000; Gilden et al., 2010; Lozowicka et al., 2014). The undesirable impacts of synthetic pesticides have raised global concern calling for research on plants with pesticidal effects on insect pests. The use of pesticidal plants is a promising tool for insect pests control hence reducing dependence on synthetic pesticides. Several studies showed that the pesticidal plant extracts are arguably effective control of insect pests on crops (Chikukura et al., 2011; Chougourou et al., 2016; Mkenda et al., 2015a; Mkindi et al., 2017; Mpumi et al., 2016; Stevenson et al., 2017; Tembo et al., 2018). Pesticidal plants are easily available, less costly and degradable in the environment and less toxic to human and non-targeted organisms (Mkenda et al., 2015a). However, there is limited information regarding to the use of pesticidal plants on the control of pre-harvest and post-harvest insects of bambara groundnuts. Therefore, the present study evaluated the effectiveness of the *Bidens pilosa*, *Lantana camara*, *Tephrosia vogelii*, *Vernonia amygdalina*, *Lippia javanica* and *Tithonia diversifolia* extracts against pre-harvest pests and dry powder on the post-harvest insects, on bambara groundnut in Tanzania.

1.2 Statement of the problem

Arthropod pests are one of the major constraints to bambara groundnuts production worldwide. For example, in countries such as Nigeria, a yield loss ranging from 43 – 71 % has been reported (Dike, 1997). As in Nigeria, Tanzania’s bambara production farmers face similar pest challenges, however, little or no literature exist on for instance types of pests and possible sustainable ecofriendly pest management techniques. Nevertheless, farmers do attempt to control pests with synthetic pesticides regardless of crops (Cooper & Dobson,
Use of synthetic pesticides have been claimed to effectively control insects pests in crops however, their uses are associated with detrimental health effects to the farmers, consumers of the crops produced and the non-target organisms (Aktar et al., 2009; Gilden et al., 2010). These constraints necessitate searching for new approaches that are cheap and eco-friendly such as the use of pesticidal plant extracts as an alternative to synthetic pesticides. Pesticidal plants have been reported to have promising results in controlling insect pests in the field and on storage (Mkenda et al., 2015a; Mkindi et al., 2017; Ogendo et al., 2003b). However, limited information is available on pesticidal plants’ effects and effectiveness against in insect pests control on bambara groundnut (as previously described) in the field and on storage. Therefore, the present study aimed at evaluating the effectiveness of the selected pesticidal plant extracts (based on their effects on other crop pests) in the control of field pests and post-harvest insect pest infestation in bambara groundnuts.

1.3 Rationale of the study

Bambara groundnut is an underutilized and under-searched crop. Thus there is limited information on for stance the pests affecting the crop, the magnitude of the damage inflicted by the pests, and the management options including the use of pesticidal plants extracts. Therefore, the present study aimed at evaluating the effectiveness of the selected pesticidal plant extracts in the control of field pests and post-harvest insect pest infestation in bambara groundnuts.

1.4 Objectives of the study

1.4.1 General objective

To evaluate the effectiveness of the pesticidal plant extracts in the control of arthropod pests in the field and post-harvest bruchids infestation in bambara groundnuts.

1.4.2 Specific objectives

(i) To evaluate the effectiveness of crude extracts of Bidens pilosa, Lantana camara, Tephrosia vogelii, Vernonia amygdalina, Lippia javanica and Tithonia diversifolia on the management of bambara groundnuts arthropod pests and their effects on beneficial insects under field conditions.
(ii) To assess the incidences and severity of different arthropod pest’s damage on bambara groundnuts treated with extracts of the pesticidal plants under field conditions.

(iii) To evaluate the effects of the application of the pesticidal plant extracts on yield and yield components of bambara groundnuts.

(iv) To evaluate the effectiveness of powder of pesticidal plants on the management of bruchids (C. maculatus) on bambara groundnuts.

1.5 Research questions

(i) What is the effectiveness of crude extracts from B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica and T. diversifolia on the management of bambara groundnut arthropod pests in field?

(ii) What are the incidences and severity of different arthropod pest’s damage on bambara groundnuts under field conditions?

(iii) What are the effects of the application of the pesticidal plant extracts on yield and yield components of bambara groundnuts?

(iv) To what extent does the dry powder from the selected pesticidal plants is effective on management bruchids on bambara groundnuts during storage?

1.6 Significance of the study

The findings of the study provided an understanding of the impact of pesticidal plant extracts for the management of pests on bambara groundnuts in the field and on storage to be used as the alternative of synthetic insecticides. Moreover, they provide useful information and awareness to the smallholder farmers and the society about the cheap, effective and environmentally benign control measures of the arthropod pests affecting the bambara groundnuts on the field and bruchids on stored bambara groundnuts.

1.7 Delineation of the study

This study assessed the effectiveness of crude extracts of selected pesticidal plants on management of field pests and powder on management of storage pests (Callosobruchus maculatus) on bambara groundnuts. As such, this study did not aim at competing pesticidal plants with the synthetic pesticides in terms of efficacy, reliability and persistence but rather as inherent agro - ecological intensification (AEI) trade - offs.
 CHAPTER TWO
LITERATURE REVIEW

2.1 Key arthropod pests affecting bambara groundnuts

Bambara groundnuts are relatively tolerant to arthropod pests and diseases (Hillocks et al., 2012). However, some literatures have reported that the crop is affected by the wide range of arthropod pests in the field, storage and fungal diseases such as Cercospora leaf spot (Cercospora spp.), powdery mildew (Erysiphe polygoni) and fusarium wilt (Fusarium oxypolygongi) (DAFF, 2016). The arthropod pests affecting the bambara groundnuts including aphids (Aphis sp.), leafhopper (Hilda patruelis), groundnut jassid (Empoasca facialis), and brown leaf beetles (O. mutabilis), red spider mites (Tetranychus sp.) (Collinson et al., 1996), pod sucking bugs (Clavigralla tomentosicollis Stäl) (Dike, 1997) in the field and bruchids (C. maculatus and C. subinnotatus) on the storage (DAFF, 2016; Mkandawire, 2007) are described hereunder.

2.1.1 Aphids (Aphis spp.)

Aphids (Aphis spp.) (Hemiptera: Aphididae) are small sap-sucking insects widely distributed in Africa. There are about 5000 species of aphids but only 450 species have been recorded on crop plants (Van & Harrington, 2017). Out of 450 species recorded on crop plants, only 100 species that are of agricultural importance (Emden & Harrington, 2017). Bambara groundnut is one of the crop infested by aphids (DAFF, 2016; Mkandawire, 2007). For instance, in Zimbabwe, aphids represent about 65% of the insect pest problem in bambara groundnuts (Heller et al., 1997). Aphids damage plants in all stages of growth from the seedlings stage to flowering (Fig. 1), pod formation and seed filling (Annan et al., 1994). On plant parts such as leaves, stems and pods, aphids form colonies damaging the crops by sucking sap from the plants during feeding or transmitting disease-causing viruses such as rosette virus or through injecting deleterious toxins into the plants (Annan et al., 1994). Heavy aphids infestation on plants, results in wilting and yellowing of the plants or causes plants death to the removal of sap from the plant (Heller et al., 1997). The main aphids control strategies in crops include cultural practices such as early planting, use of resistant varieties (Ofuya, 1997). Other aphids control strategies include physical control and application of chemical insecticides such as phosphamidon, dimethoate, thiometon pirimicarb. The use of synthetic pesticides to control in agriculture is associated with the undesirable effects therefore their use is discouraged
(Ofuya, 1997). The biological control such as the use of natural enemies such as parasitic wasps, hoverfly larvae, lacewings and ladybird beetles which predate on aphids help in suppressing the population of aphids (Emden & Harrington, 2017). Pesticidal plants, on the other hand, have provided promising results in aphid’s control in other crops including common beans. For example, Mkindi et al. (2017) reported that pesticidal plants such as B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica and T. diversifolia were effective against aphids (Aphis fabae) on common beans. However, there is very limited information on the abundance of aphids on bambara groundnuts and the damage caused and use of pesticidal plants in aphids control on bambara groundnuts. Therefore, future research should focus on quantifying the abundance of aphids on bambara groundnuts and the damage caused by them in different cropping systems and to test the effectiveness of the available pesticidal plants to be used as an alternative of synthetic pesticides in Tanzania.

2.1.2 Groundnut leafhopper (Hilda patruelis Stal)

The groundnut hopper, Hilda patruelis Stal (Homoptera: Tettigometridae) are polyphagous sucking bug widely distributed in Africa (Minja et al., 1999; Rao et al., 2013). Groundnut leafhopper is one of the important insect pests of bambara groundnuts severely affecting their productivity (DAFF, 2016; Uddin et al., 2017). They usually attack plants at the ground and or below the ground level (Minja et al., 1999). During their feeding process, Hilda bugs tend to inject toxic saliva on the plants resulting in withering and ultimately dying of the plants. They are usually noticed by the presence of the colonies of black ants which tend to protect them (Minja et al., 1999). The leafhoppers and ants coexist in symbiotic relationship where the leafhoppers produce honey-dew which provide food for the ants while ants protect the leafhoppers against predators (Minja et al., 1999). The adult leafhoppers damage the crop by sucking sap from the stem, pegs and pods resulting in wilting of the plants (Hill, 2008). The affected plants turn yellow, wilt and die due to sap-sucking by the hoppers (Heller et al., 1997; Minja et al., 1999). Although, it is regarded as a minor pest, sporadic infestation during the dry season may lead to significant loss of yield if left uncontrolled (Minja et al., 1999). In Tanzania, there is a lack of information on this insect due to little research attention on bambara groundnuts as it is considered as an under-researched orphan crop (Azam et al., 2001). Therefore, further research should focus on determining the abundance and assessment of the impact of H. patruelis on bambara groundnuts grown in different cropping systems and patterns.
2.1.3 Foliage beetles (*Ootheca mutabilis, O. bennigseni*)

Foliage beetles (*O. mutabilis* and *O. bennigseni*) (Coleoptera: Chrysomelidae) are foliage eating insects that are widely distributed in southern and eastern Africa including Tanzania (Abate & Ampofo, 1996). Leaf beetles are important insects affecting, common beans, cowpea and bambara groundnuts (Abate & Ampofo, 1996; DAFF, 2016; Grobbelaar, 2008). The beetles feed on root tissue and seedlings, make holes in the foliage of host plants (Fig. 2) and often feed on blossoms, resulting in crop losses usually when the crop is at the seedling stage. *Ootheca mutabilis and Ootheca bennigseni* are also responsible for transmitting plant viruses (Grobbelaar, 2008). The infestation by foliage beetles is most severe on young plants nonetheless it may persist up to post-flowering. The adult beetles feed on leaves reducing the photosynthetic activity of the plant and may even cause the death of the plants especially if there is a severe attack on the growing points (Abate & Ampofo, 1996). In common beans, the yield losses of 18-31% attributed by foliage beetles in Tanzania have been reported (Abate & Ampofo, 1996). Unfortunately, in Tanzania, there is published information on the magnitude of the impact of this foliage beetles on bambara groundnuts. Therefore, future research is needed to determine the damage inflicted by leaf beetles and evaluate the efficacy of pesticidal plants on control of these insect pests.

2.1.4 Groundnut jassids (*Empoasca fascilis*)

Groundnut jassids *Empoasca fascilis* (Homoptera: Cicadellidae) are small green insects widely distributed in Africa (Rao et al., 2013; Srinivasan, 2014). *Empoasca fascilis* is one of the important insect pests of bambara groundnuts in Africa (DAFF, 2016). The adults and nymphs of jassids pierce and suck on the lower surfaces of the leaf leading to the yellowing of the leaves (Rao et al., 2013). The jassids population growth is generally enhanced by dry and humid conditions. The infestation of many jassids on one leaf may result in yellow spots followed by crinkling, curling, bronzing and drying of the plants (Rao et al., 2013). A yield loss of 3.5 - 39.5% has been reported to be inflicted by jassids in soybeans depending on the susceptibility of the variety (Nasruddin & Gassa, 2014). The management strategies include cultural practices such as intercropping with non-legume crops and use of systemic insecticides. However, the use of synthetic insecticides kills the natural enemies which prey on the adult and nymphs regulating the population of jassids. Thus, future research is needed to look for strategies that have less impact on natural enemies such as the use of extracts from the pesticidal plants.
2.1.5 Pod sucking bugs (*Clavigralla tomentosicollis* Stål)

Pod sucking bugs, *C. tomentosicollis* Stål (Hemiptera: Coreidae) are pods sucking bugs predominantly distributed in tropics and sub-tropics of Africa (Srinivasan, 2014). Pod sucking bugs are one of the important pests of bambara groundnuts (Dike, 1997). The nymphs and adults pierce and bugs suck the sap from the young pods leading to the deformation of seeds, necrosis, premature drying of the pods and poor seed formation which ultimately results in low grain yield (Abate & Ampofo, 1996; Srinivasan, 2014). They also feed on stems, leaves and floral buds (Srinivasan, 2014). The insect can cause grain yield loss ranging from 20 - 100% when left uncontrolled on susceptible crops especially during prolonged dry weather (Aliyu et al., 2007). Cultural practices such as intercropping legumes including bambara groundnuts with cereals can reduce the bugs infestation (Srinivasan, 2014). The biological control agents such as the use of *Gryon fulviventris* parasitoid can control *C. tomentosicollis* in Africa (Srinivasan, 2014). On the other hand, synthetic insecticides can also be used to control bugs, however, they may kill even beneficial insects such as parasitoids *G. fulviventris* (Srinivasan, 2014). Pesticidal plants such *B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica* and *T. diversifolia* on the other hand have provided effective control of insect pests on common beans insect pests including *C. tomentosicollis* (Mkindi et al., 2017). Thus, future research should focus on testing the effectiveness of these pesticidal plants to control pod bugs on bambara groundnuts.

2.1.6 Red spider mites (*Tetrunychus* sp.)

Red spider mites, *Tetrunychus* sp. (Acari: Tetranychidae) are highly polyphagous mites originated in Eurasia but they are now widely distributed worldwide (Raworth et al., 2001). Red spider mites affect a wide range of crops including tomato, cucumber, pepper, rose, strawberry, currant, peach, grapes (Raworth et al., 2001), common beans (Abate & Ampofo, 1996) and bambara groundnuts (Collinson et al., 1996). The damage of crops inflicted by red spider mites depends on the ability of the plant to resist damage. On susceptible crop, spider mites feed on leaves undersides by extracting the plant's sap using their long needle-like mouthparts resulting in the formation of brownish spots and often form webs on plants leaves (Abate & Ampofo, 1996). In severe infestation of mites, the leaves dry and dry off resulting in the wilting of the entire plant (Srinivasan, 2014). The loss of yield of up to 100% has been reported to be caused by spider mites on infested tea (Mamun & Ahmed, 2011) and tomato.
Unfortunately, there is limited information on damage caused by red spider mites on bambara groundnuts. The infestation of spider mites population is influenced by environmental factors such as low relative humidity, high temperature, drought and long sunshine hours (Ahmed et al., 2012). Bagarama (2016) reported that spider mites are difficult to control. Farmers often use ineffective broad-spectrum synthetic pesticides to control spider mites resulting in pest resistance (Bagarama, 2016). The use of broad-spectrum synthetic pesticides tends to kill the natural enemies which would regulate the population of the spider mites (Srinivasan, 2014). Moreover, predatory mites such as *Phytoseiulus persimilis*, *Amblyseius womersleyi* and *A. fallacies* (Acari: Phytoseiidae) are effective to control red spider mites under controlled conditions and high relative humidity (Srinivasan, 2014). However, the synthetic insecticides applied also kills beneficial mites. Pesticidal plants, on the other hand, have been reported to reduce spider mites without or with little harm to the natural enemies. For instance, studies by (Muzemu et al., 2011) have revealed pesticidal efficacy of the *L. javanica* and *Solanum delagoense* on red spider mites on rapes and tomatoes (Muzemu et al., 2011). It was found that both *L. javanica* and *S. delagoense* reduced mites by 66.5% and 55% respectively. Despite of the reported effectiveness of, *L. javanica* and *S. delagoense* on spider mites on rapes and tomato, however, there is no published information on their effectiveness on bambara groundnuts spider mites. Thus future research is recommended to investigate the efficacy of indigenous pesticidal plants on bambara groundnut spider mites.

2.1.7 Bruchids, *Callosobruchus maculatus* (F.) and *Callosobruchus subinnotatus* (Pic)

Bruchids, *C. maculatus* and *C. subinnotatus* (Coleoptera: Bruchidae) are serious pests of grain bambara groundnuts in Africa (Ajayi & Lale, 2000; Dike, 1997). *Callosobruchus maculatus* are widely distributed and believed have originated in Africa while *C. subinnotatus* is mainly localized in West Africa (Labeyrie, 2013). These two bruchids species often infest grain bambara groundnuts simultaneously. When these two species simultaneously infest bambara grains, they tend to exhibit interspecific competition where *C. maculatus* dominates over *C. subinnotatus* (Lale & Vidal, 2001; Maina & Lale, 2004). It is reported that *C. maculatus* is the most destructive species due to its shorter life cycle and high reproductive potential and it often infests a wide range of legume grains while *C. subinnotatus* infest only bambara grains (Ajayi & Lale, 2000; Lale & Vidal, 2001). During co-infestation, *C. maculatus* can cause the extinction of *C. subinnotatus* in multiple generations (Lale & Vidal, 2001). Bruchids affect bambara groundnuts from the field to the
storage. Being field to storage pests, bruchids infestation commences in the field during the pod's stage whereby the females lay their eggs on developing seeds or pods or during the harvesting when the pods are left in the field to dry (Ajayi & Lale, 2000; Nyamador et al., 2016). Bruchids on stored bambara groundnuts grains, reduce the quality and quantity of grains and reduce the seeds germination potential and market value of the grains. The grain loss of up 99% has been reported when grains of susceptible variety is left unprotected with insecticide (Umar & Turaki, 2014). The storage infestation influenced by the level of primary infestation from the field thus the proper strategy of protection of bambara groundnuts from bruchids infestation starts by prevention of field infestation and post-harvest infestation during storage (Lale & Vidal, 2001). Various strategies are applied to control bruchids such as cultural control measures, breeding for resistance, synthetic insecticides and pesticidal plants (Ajayi & Lale, 2000). The pesticidal plants powder has been reported to be effective for control of storage insects and does not cause an undesirable impact on the health of consumers, applicators and nor-target organisms (Chikukura et al., 2011; Chougourou et al., 2016). However, there is limited information on the use of pesticidal plants for control of storage insects on bambara groundnuts. Thus, more research is needed to determine the efficacy of pesticidal plants in the control of bruchids in bambara groundnuts.

2.2 Prospects of pesticidal plants in bambara groundnut arthropod pest control in the field and storage

Pesticidal plants contain a mixture of bioactive compounds that act as feeding deterrents, repellents on insects or they tend to interfere with insect development (Belmain et al., 2013). Plants with pesticidal effect have been used by farmers for decades for pest control in crops or livestock (Table 1) before and after the introduction of synthetic pesticides (Anjarwalla et al., 2016). Unlike synthetic pesticides, pesticidal plants are relatively less expensive and are ecofriendly to the environment, non-target organisms and humans (Anjarwalla et al., 2016; Mkenda et al., 2015a). This review has focused on the chemical compounds, potential in controlling arthropod pests in the field and storage of seven selected candidate pesticidal plants including B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica and T. diversifolia and C. dichogamus.
<table>
<thead>
<tr>
<th>Pesticidal plant</th>
<th>Crop/pest (s) controlled</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrysanthemum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cinerarifolium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azadirachta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>indica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black jack,</td>
<td>Common beans insect pests: Ootheca mutabilis and <em>O. bennigseni</em>, Epicauta albovittata</td>
<td>Mkindi <em>et al.</em> (2017)</td>
</tr>
<tr>
<td>Bidens pilosa</td>
<td>and <em>E. limbatipennis</em>, Clavigralla tomentosicollis, and <em>C. hystricodes</em></td>
<td></td>
</tr>
<tr>
<td>Mexican marigold,</td>
<td>Cabbage: <em>Brevicoryne brassicae</em></td>
<td>Phoofolo <em>et al.</em> (2013)</td>
</tr>
<tr>
<td><em>Tagetes minuta</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tickberry</td>
<td>Maize weevil: <em>Sitophilus zeamais</em></td>
<td>Ogendo <em>et al.</em> (2003a)</td>
</tr>
<tr>
<td>Lantana camara</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Nicotiana tabacum</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish poison,</td>
<td>Common beans insect pests: <em>O. mutabilis</em> and <em>O. bennigseni</em>, Epicauta albovittata</td>
<td>Mkindi <em>et al.</em> (2017)</td>
</tr>
<tr>
<td><em>Tephrosia vogelii</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bitter leaf,</td>
<td>Cowpea beetle: <em>C. maculatus</em></td>
<td>Green <em>et al.</em> (2017)</td>
</tr>
<tr>
<td><em>Vernonia amygdalina</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lippia javanica</td>
<td>Common beans insect pests: <em>O. mutabilis</em> and <em>O. bennigseni</em>, <em>E. albovittata</em> and <em>E. limbatipennis</em>, <em>C. tomentosicollis</em> and <em>C. hystricodes</em></td>
<td>Mkindi <em>et al.</em> (2017)</td>
</tr>
<tr>
<td>Mexican sunflower,</td>
<td>Cowpea beetle: <em>C. maculatus</em></td>
<td>Green <em>et al.</em> (2017)</td>
</tr>
<tr>
<td><em>Tithonia diversifolia</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus sp.</em></td>
<td>Cereals: <em>S. oryzae</em></td>
<td>Campolo <em>et al.</em> (2018)</td>
</tr>
<tr>
<td>Garlic,</td>
<td>Maize: <em>S. zeamais</em></td>
<td>Chaubey (2017)</td>
</tr>
<tr>
<td><em>Allium sativum</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Derris elliptica</em></td>
<td></td>
<td><em>(Moyo et al. (2006)</em></td>
</tr>
<tr>
<td>Papaya,</td>
<td>Mustard <em>Lipaphis erysimi</em></td>
<td>Baroacha <em>et al.</em> (2014)</td>
</tr>
<tr>
<td><em>Carica papaya</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Croton dichogamus</em></td>
<td></td>
<td>Qwarse <em>et al.</em> (2018)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.2.1 The chemical and insecticidal potential of *Croton dichogamus*

*Croton dichogamus* Pax is a naturally growing shrub belonging to the family Euphorbiaceae extensively distributed in tropics and subtropics such as Kenya, Uganda, Ethiopia, Mozambique, Madagascar and Tanzania (Aldhaher *et al.*, 2017; Xu *et al.*, 2018; Plate 1). In Africa, America and Asia croton species are used as traditional medicines for the treatment of various ailments such as fever, diabetes, dysentery, wounds, ulcers, malaria, intestinal worms, inflammation, hypercholesterolemia, digestive problems, constipation, cancer, weight loss and pains (Salatino *et al.*, 2007). In Kenya and Tanzania, *C. dichogamus* is used as a dietary milk and soup supplement. The smoke from the Croton is inhaled during the treatment of respiratory infections. In addition, the plant has also been reported to be used to treat chest pains, malaria, arthritis, gonorrhea and stomachache in Kenya (Aldhaher *et al.*, 2017).

Plate 1: The picture of *C. dichogamus*, a pesticidal plant

The photochemistry of the plant is generally diverse possessing the compounds such as crotodichogamoin A and B (Fig. 1), crotofolanes, halimes, crothalimene A and B,
crotohaumanoxide, aleuritolic, depressin, casbane and sesquiterpenoid are isolated from the roots of *C. dichogamus* (*Aldhaher et al.*, 2017; *Xu et al.*, 2018). Most of the croton species are rich in terpenoids (*Salatino et al.*, 2007), a compound with insecticidal properties (*Castilhos et al.*, 2018; *Dambolena et al.*, 2016). *Silva et al.* (2018) studied the effectiveness of the ethanolic extracts from the leaves and stems of *Croton rhamnifolius*, *C. jacobinensis*, *C. sellowii* and *C. micans* against the diamondback moth (*Plutella xylostella* L) on kales. It was found that the *C. rhamnifolius* leaf had more lethal effect (LC=14.95 mL⁻¹) than the stem (LC=42.40 mL⁻¹) and *C. sellowii* stem was found to have the lowest lethal effect (LC=1252 µg mL⁻¹). In Tanzania, the plant is used by agro-pastoral societies in Mbulu District as a pesticide for controlling storage insect pests, medication of teeth infections and urinary tract infection (*Qwarse et al.*, 2018). Despite *C. dichogamus* being used traditionally by agro-pastoral societies in Mbulu district in Tanzania, proper application rates have not been established for optimized application. Therefore, future research is needed to establish its dosages for proper insect pest control.

![Crotodichogamoin A and B](image)

**Figure 1:** Chemical structure of crotodichogamoin A and B from *C. dichogamus* roots (*Aldhaher et al.*, 2017)

### 2.2.2 The chemical and insecticidal potential of *Tithonia diversifolia*

*Tithonia diversifolia* commonly known as Mexican sunflower is a prolific flowering shrub belonging to the family Asteraceae originated from central and north America (*Ajao & Moteetee*, 2017). Currently, *T. diversifolia* (Plate 2) is widely distributed along with the farms, roads, rivers and hills of humid and sub-humid tropics of Africa, Central America and South America (*Jama et al.*, 2000; *Tagne et al.*, 2018). In many parts of Africa, the extracts from the *T. diversifolia* plant is traditionally used as medicine for the cure of many ailments including wounds, skin diseases, stomachache, malaria, diabetes, sore throat, fever and liver
pains (Moronkola et al., 2007; Tagne et al., 2018) and insect pests control (Mkindi et al., 2017). The medicinal and insecticidal properties of the *T. diversifolia* are attributed by the presence of phytochemical constituents including sesquiterpene lactones tagitin A, tagitin B, tagitin C, tagitin D and tagitin H (Fig. 2) (Ajao & Moteetee, 2017; Green et al., 2017). Several authors including (Green et al., 2017) reported the insecticidal potential of *T. diversifolia* against cowpea bruchids *C. maculatus*. It was found that the toxicity of crude extracts of *T. diversifolia* against bruchids was concentration-dependent. Yet, the crude extracts showed no significant effect on the oviposition despite the variation in concentration. Other studies by Mkenda et al. (2015a) and Mkindi et al. (2017) found that the leaf extracts of the *T. diversifolia* was effective against the insect pest of common beans such as bean foliage beetle (*O. mutabilis* and *O. bennigseni*), aphids (*Aphis fabae*) and flower beetle (*Epicauta albovittata* and *E. limbatipennis*). The application of *T. diversifolia* as pesticide reduces the cost incurred on expensive synthetic pesticides resulting in the high marginal rate of returns from farming. For example, the use of *T. diversifolia* is reported to provide the marginal rate of return of 5.32 USD/ha higher than 4.06 USD/ha obtained when synthetic pesticide is used (Mkenda et al., 2015a). Additionally, the leaves of the *T. diversifolia* contain mineral nutrients about 3.5%N, 0.37%P and 4.1%K on dry matter basis so when used as green manure replenishes soil nutrients enhancing the growth and yield of the crops (Jama et al., 2000). Moreover, foliar spraying of the extract from these *T. diversifolia* as a pesticide it also provide additional nutrients to the crop in the form of foliar fertilizer (Cenny et al., 2013), thus, resulting to high yield of the crop. Furthermore, plants are also used as animal fodder (Osuga et al., 2012).
Plate 2: The picture of *T. diversifolia*, a pesticidal plant

Therefore, presence of the bioactive compounds in these plants and proven pesticidal potential against arthropod pests of legumes (Green *et al.*, 2017; Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017) gives the insight to investigate its effectiveness in control of pre-harvest and post-harvest insect pest of bambara groundnuts.
Figure 2: Chemical structure of sesquiterpene lactones tagitin A, tagitin B, taginin C taginin F and taginin 2 alpha-hydroxytirotundin, taginins A isomer and dehydrated taginins A (Green et al., 2017; Miranda et al., 2015; Zhao et al., 2012)
2.2.3 The chemical and insecticidal potential of *Lantana camara*

*Lantana camara* (Plate 3) is an ornamental plant in the family Verbenaceae originated from America. It is widely spread in tropical and subtropical regions including Eastern Africa (Shackleton et al., 2017). In many parts of the world, *L. camara* is considered an invasive weed (Goncalves et al., 2014; Shackleton et al., 2017; Zoubiri & Baaliouamer, 2012).

Plate 3: The picture of *L. camara*, a pesticidal plant

In some countries, *L. camara* is used in preparation of the folk medicine for cure of ailments diseases such as ulcers, rheumatism, tetanus, malaria, cancer, ulcers, cancer, eczema, high blood pressure, sores and measles among others (Hernández et al., 2003; Kalita et al., 2012; Kurade et al., 2010; Magassouba et al., 2007). *Lantana camara* is regarded as poisonous to livestock such as cattle, goats, sheep, dogs and horses (Mpumi et al., 2016). The toxicity of *L. camara* to animals is caused by the presence of pentacyclic triterpenoids (Fig. 3) which damage liver and generalized weakness, diarrhea, vomiting and notorious to cause photosensitivity (Durbesula et al., 2015). In humans, the toxicity of *L. camara* is undetermined but several studies have suggested that ingesting green unripe fruits are toxic (Durbesula et al., 2015; Sharma et al., 2007). However, other studies have reported that ingestion of ripe fruits of *L. camara* poses no risk to humans (Durbesula et al., 2015; Sharma et al., 2007). *Lantana camara* has been reported to have insecticidal properties against
several insect pests of stored grains. For example, the study conducted in Kenya by (Ogendo et al., 2003a) revealed the insecticidal potential of leaf powder from *L. camara* against maize weevil (*S. zeamais*). The findings from their study showed that after 21 days *L. camara* at the rate of 7.5-10 % (w/v) resulted in 82.7% insect mortality. Moreover, another study by Rajashekar et al. (2014) reported the potential of *L. camara* in control of *S. oryzae* (L.) *C. chinensis* (Fab.) and *Tribolium castaneum* (Herbst.). Despite the potential of *L. camara* reported in other crops pests, there is a need to conduct more studies to understand the potential of *L. camara* against different insect pests on bambara groundnuts both in the field and on storage.

![Chemical structures of Lantadene (Pentacyclic triterpenoids)](image)

Figure 3: Chemical structures of Lantadene (Pentacyclic triterpenoids) (Mpumi et al., 2016; Sharma et al., 2007)

2.2.4 The chemical and insecticidal potential of *Bidens pilosa*

*Bidens pilosa* L. is an annual herb originated from South America and widely distributed around the tropical and subtropical regions (Bartolome et al., 2013; Lima Silva et al., 2011). *Bidens pilosa* is regarded as a noxious weed in the agricultural fields (Arthur et al., 2012; Plate 4). In sub-Saharan countries, the young tender leaves of *B. pilosa* are consumed as a vegetable in times of food scarcity (Arthur et al., 2012). In many parts of the world including Africa, Asia and tropical America; *B. pilosa* is used as medicinal plant in treatment of inflammation, bacterial infection, antioxidant, liver protection, regulating blood pressure and blood sugar (Arthur et al., 2012; Ashafa & Afolayan, 2009; Deba et al., 2008; Geissberger & Séquin, 1991). The medicinal role offered by this plant is a result of the presence of bioactive
compounds. For instance, the antimicrobial and antimalarial function of *B. pilosa* is due to the presence of polyacetylenes in the plant (Geissberger & Séquin, 1991).

**Plate 4: The picture of *B. pilosa*, a pesticidal plant**

Major bioactive compounds identified from leaves and flowers of the *B. pilosa* includes sesquiterpenes germacrene-D and β-caryophyllene and τ-cadinene (Deba *et al.*, 2008; Lima Silva *et al.*, 2011) (Fig. 4). *Bidens pilosa* is also reported to have anti-insect function. For example, a study conducted by Goudoum *et al.* (2016) revealed the insecticidal potential of essential oils from the leaves of *B. pilosa* against *C. maculatus*. Renuka *et al.* (2014) investigated the toxicity of methanol and acetone extracts of *B. pilosa* against stored pests of kidney beans, the *A. obtectus* (Say) and *Zabrotes subfasciatus* (Boheman) (Coleoptera: Chrysomelidae). Both acetone and methanol extracts from the *B. pilosa* plant were found to cause 100% mortality of *A. obtectus* and *Z. subfasciatus*. Moreover, other studies conducted by Mkindi *et al.* (2017) and Tembo *et al.* (2018) revealed the insecticidal potential of *B. pilosa* against insect pests of common beans such as foliage beetles (*O. mutabilis* and *O. bennigseni*), flower beetle borers (*Epicauta albovittata* Gestro and *E. limbatipennis* Pic), aphids (*A. fabae*) and pod suckers (*Clavigralla spp.*). In spite of the fact that the insecticidal function of the plant has been reported by many authors (Goudoum *et al.*, 2016; Mkindi *et al.*, 2017; Tembo *et al.*, 2018) however, it has not been sufficiently tested on bambara groundnut pests. Thus, future research needs to be conducted to determine efficacy *B. pilosa* on insect pests on bambara groundnuts.
Figure 4: Sesquiterpenes germacrene-D (Yang et al., 2005) and (b) β-caryophyllene (Gertsch et al., 2008) from B. pilosa

2.2.5 The chemical and insecticidal potential of Tephrosia vogelii

*Tephrosia vogelii* Hook. f. (Plate 5) is the herb belonging to the Family Leguminosae native to tropical Africa that is highly distributed in tropical America and South and Southeast Asia mainly used as fish poison (Dzenda et al., 2009). *Tephrosia vogelii* is also used as a pesticide to control pests on animals and on crops on the field and storage and also enrich soil nutrients (Stevenson et al., 2012). The phytochemical screening of *T. vogelii* showed that the plant possesses diverse bioactive chemical compounds including three chemotypes (Fig. 5). The chemotype 1 (C1) which contains rotenoids required for pest control and chemotype 2 (C2) which do not contain rotenoids (Belmain et al., 2012; Stevenson et al., 2012). However, it is reported that rotenoids (deguelin, tephrosin, α-toxicarol and sarcologbine) differ in their effectiveness against insect pests. Rotenone is the most active rotenoid than deguelin, tephrosin while obovatin 5-methyl ether found in chemotype 2 is not active (Belmain et al., 2012). The Chemotype 3 (C3) is a hybrid of the chemical profiles of the Chemotype 1 and chemotype 2 (Mkindi et al., 2019).
Several studies have reported the insecticidal potential of the active chemical compounds of *T. vogelii*. For example, a study conducted by Ogendo *et al.* (2003a) revealed that *T. vogelii* leaf powder killed maize 85.0 – 93.7% of weevil (*S. Zeamais*) in stored maize grain. It was found that the mortality of maize weevil caused by *T. vogelii* leaf powder was proportional to the exposure time and concentration. Closely related findings were reported by Koon and Dorn (2005) when they investigated the potential of extracts from *T. vogelii* for the control of bruchids on stored legumes. Their study showed that the extracts from *T. vogelii* had insecticidal potential against bruchid species (*A. obtectus, C. maculatus* and *C. chinensis*) on stored legumes.

**Plate 5: The picture of *T. vogelii* a pesticidal plant**

Moreover, the use of *T. vogelii* in controlling common bean pests has been reported to provide high marginal rate of return 5.62 (USD/ha) as compared with synthetic pesticide lambda-cyhalothrin pyrethroid (Karate) 4.06 USD/ha (Mkenda *et al.*, 2015a). The low marginal rate of return (USD/ha) for synthetic pesticides is due to its high market price and ultimately high marginal cost than when *T. vogelii* was used. Despite the insecticidal and economic benefits offered when *T. vogelii* is used to control pests on crops such as common beans, however, there is limited information on its potential in insect control on bambara groundnuts. Therefore, future research should be conducted to determine potential of *T. vogelii* for bambara groundnuts insect control on the field and on storage.
2.2.6 The chemical and insecticidal potential of *Vernonia amygdalina*

*Vernonia amygdalina* Del, (Plate 6) is a small perennial shrub belonging to the family Asteraceae that is widely distributed in tropical Africa. *Vernonia amygdalina* is commonly known as bitter leaf because its bitter taste (Ijeh & Ejike, 2011). The bitter taste is attributed to the presence of anti-nutritional factors in *V. amygdalina* such as alkaloids, saponins, glycosides and tannins (Bonsi *et al.*, 1995; Clement *et al.*, 2014). *Vernonia amygdalina* have many traditional uses in African countries. In Nigeria, the leaves of bitter leaf are used as a vegetable or as a spice in a soup whereby the bitterness of the leaves is reduced to the desired level by macerating in hot water (Clement *et al.*, 2014; Farombi & Owoeye, 2011). In Ethiopia, the leaves of *V. amygdalina* are used as hops in preparing tela beer (Farombi & Owoeye, 2011). The *V. amygdalina* leaves are consumed due to their antioxidant benefits.
(Alara et al., 2017; Igile et al., 1994). In most African countries V. amygdalina is used as a folk medicine as remedies against ailments such as emesis, loss of appetite, diabetes, nausea, dysentery and other gastrointestinal tract problems, sexually transmitted diseases, diabetes mellitus (Farombi & Owoeye, 2011) and antimalarial (Masaba, 2000).

Plate 6: The picture of V. amygdalina, a pesticidal plant

The phytochemical investigation of the leaves of V. amygdalina revealed presence of number of bioactive compounds such as sesquiterpene lactones including the vernolide and vernodalol (Fig. 6) (Erasto et al., 2006; Igile et al., 1994), flavonoids such as luteolin, luteolin 7-O-glucuronide, luteolin 7-O-glucosides, steroid glycosides, and vernonioside A, B, A1, A2, A3, B2, B3 and A4 (Farombi & Owoeye, 2011; Igile et al., 1994). The sesquiterpene lactones found in V. amygdalina have insect antifeedant, antitumoral, antifungal, and cytotoxic properties (Erasto et al., 2006). Several studies have reported the insecticidal potential of leaf powders of V. amygdalina against C. maculatus (F.) (Akunne et al., 2014), beans weevil (A. obtectus) (Adeniyi et al., 2010) and maize weevil (S. zeamais) (Asawalam & Hassanali, 2006) and field insects of common beans (Aphis fabae), bean foliage beetle (O. mutabilis) and O. bennigseni), flower beetle (Epicauta albovittata and E. limbatipennis) and pod suckers (Clavigralla tomentosicollis, C. schadabi and C. hystricodes) in a study conducted in Tanzania and Malawi (Mkindi et al., 2017). However, despite its potential in controlling insects in other crops such as common beans, future research is needed to test the efficacy of V. amygdalina extracts in controlling field and storage insect pests of bambara groundnuts.
2.2.7 The chemical and insecticidal potential of *Lippia javanica*

*Lippia javanica* (Burm F.) Spreng (Plate 7) is an erect woody perennial herb belonging to the family Verbenaceae. *Lippia javanica* is naturally growing in the bushes, along the roadsides, hillsides and farms in eastern, central and southern Africa and in the Indian subcontinent (Maroyi, 2017; Mwanauta *et al.*, 2014; Pascual *et al.*, 2001). In many African countries and Indian subcontinent, *L. javanica* are traditionally used as herbal tea due to its ethno-medicinal properties for cure of ailments like malaria, fever, colds, cough, healing wounds, diarrhea, chest pains, bronchitis, asthma, skin diseases and repelling mosquitos (Endris *et al.*, 2016). In Kenya, the leaves and twigs of *L. javanica* are used as food additives whereas in India, leaves are used as a leafy vegetable. In Botswana, South Africa and Zimbabwe; the leaves, stems, and twigs are used in preparations of the herbal tea (Maroyi, 2017).
Plate 7: The picture of *L. javanica*, a pesticidal plant

The phytochemical analysis of *L. javanica* revealed the presence of camphor as the major component with minor components such as camphene, α-pinene, eucalyptol, 2-carene and 2-carene (Mkenda *et al.*, 2015a). The camphor (Fig. 7) a monoterpenoid commonly found in *Cinnamomum camphora* is reported to have insecticidal potential (Chen *et al.*, 2018; Gillij *et al.*, 2008; Mkenda *et al.*, 2015a; Singh *et al.*, 2014; Tembo *et al.*, 2018). The insecticidal function of *L. javanica* has been reported by several authors. For example, studies by Mkenda *et al.* (2015a), Mkindi *et al.* (2017) and Tembo *et al.* (2018) reported the insecticidal property of *L. javanica* against field insects of common beans such as bean foliage beetle (*O. mutabilis* and *O. bennigseni*), aphids (*Aphis fabae*) and flower beetle (*Epicauta albovittata* and *E. limbatipennis*). Another study conducted in Zimbabwe revealed that the aqueous leaf extracts of *L. javanica* have acaricidal activity against cattle ticks and acute oral toxicity in mice (Madzimure *et al.*, 2011). Their study found that the acaricidal effect was dependent on the dose of the extract and exposure time. A study by Wafula *et al.* (2019) as well revealed the effectiveness of aqueous extracts of *L. javanica* leaves against the cowpea aphids. Their study established that 10% (w/v) extracts from the dried leaves powder significantly reduced the aphids infestation on cowpeas. Furthermore, the leaf powders demonstrated insecticidal potential against storage insect pests of maize and cowpeas including *S. zeamais*, *C. maculatus*, *Prostephanus truncates*, *Tribolium spp* and *Sitotroga cerealella* (Chikukura *et al.*, 2011). Despite the fact that *L. javanica* contains bioactive compounds proved with
insecticidal potential, however, it has not been evaluated against insect pests of bambara groundnuts. Therefore, future research is needed to investigate its potential against the pre-harvest and post-harvest insect pests of bambara groundnuts.

Figure 7: Chemical structure of camphor (Yim et al., 2014)
CHAPTER THREE

MATERIALS AND METHODS

3.1 Study location

The study to assess the effectiveness of selected pesticidal plants against field and storage pests of bambara groundnuts was set at Nelson Mandela Institution of Science and Technology (NM-AIST), Arusha, Tanzania.

3.2 Pesticidal plant extracts preparation

The fresh leaves of *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia* were collected from natural habitat in Arusha and Moshi region in Tanzania. These sites were selected based on the available grey information indicating the availability of these plants. Crude extracts from these plants were prepared as described by Anjarwalla *et al.* (2016) and Mkenda *et al.* (2015a). In brief, the pesticidal plants leaves from each plant were air-dried under the shade separately. Then the leaves were separately crushed using an electric grinding mill to make the powder, which was stored in plastic buckets in dark condition to avoid degradation of bioactive compounds until when required for subsequent applications. Plant extracts were prepared from dry leaves powder using clean tap water in the concentration of 10% (w/v) and 0.1% soap was added during the extraction of the active compounds from the pesticidal plant materials in water. The mixture was left for 24 hours and filtered twice using the clean cloth to remove large particles of plant materials prior to spraying.

3.3 Experimental design and treatments for the field experiment

The field was prepared by clearing the bush and the land was ploughed and disc harrowed prior to planting of the bambara groundnut seeds. The bambara groundnuts seeds (Tanbam) used in this experiment were obtained from the Tanzania Agricultural Research Institute (TARI-Naliendele). Two seeds were planted per hole in 60 cm by 10 cm inter-row and intra-row respectively in 5 x 5 m plot. The seeds were planted on 12<sup>th</sup> April 2019. After emergence plants were thinned leaving one plant per hole. A randomized complete block design (RCBD) was used to set the field experiment with 8 treatments replicated 4 times. Treatments consisted of six (6) pesticidal plants leaf extracts namely *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia*. The experimental design was a randomized complete block design (RCBD) with eight treatments and four replications. The experimental plan was laid out in a randomized complete block design (RCBD) with eight treatments and four replications. The treatments consisted of applicators for spraying pesticidal plants leaf extracts.
*amygdalina, L. javanica* and *T. diversifolia*, synthetic insecticide (lambda-cyhalothrin) as the positive control and untreated plot as the negative control. The distance between replication was 2 m and the distance between plots was 1 m (Appendix 1). The pesticidal plant extracts were sprayed 2 weeks after the emergence of the bambara groundnuts throughout the growing season at the interval of 7 days. Positive control karate (lambda-cyhalothrin 5% EC), Syngenta, was applied by following the manufacturer’s recommendation. The pesticidal plants extracts were sprayed above and under the leaves using 15 L Knapsack sprayers during the evening to avoid direct sunlight which might cause decomposition of bioactive compounds to maximize contact with insects as described by Anjarwalla *et al.* (2016) and Mkenda *et al.* (2015a). The earthing up was done at 90 days after planting.

### 3.4 Data collection

#### 3.4.1 Evaluation of the effectiveness of crude extracts of selected pesticidal plants on the management of bambara groundnuts pests under field conditions and their effects on beneficial arthropods

The arthropod pests and beneficial arthropods were observed by randomly selecting five (5) inner plants in each plot. The pests and beneficial arthropods were identified and their numbers counted before application of the treatments. The abundance/numbers of small arthropods such as aphids and red spider mites were scored using the categorical index of 1-5; where, 0 = none; 1 = few and scattered individuals; few isolated colonies; 3 = several isolated colonies; 4 = large isolated colonies; and 5 = large continuous colonies (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017). Large arthropods such as foliage beetles, mealybugs and leafhoppers and ladybird beetle, spiders, hoverflies and wasps were counted. Unidentified pests were collected and preserved in 70% ethanol for further identification by Tropical Pesticides Research Institute (TPRI).

#### 3.4.2 Assessment of incidences and severity of different arthropods damage on bambara groundnuts

Five (5) inner plants were randomly selected in each plot where the number of plants affected was counted and the incidence of the key pests was determined as the proportion of the affected plants sampled to the total number of plants sampled in each plot. The plant damage severity from key arthropod pests was determined by whole plant assessment of the five (5)
randomly selected inner plants using a scales 0 - 4; where, 0 = 0 % damage, 1 = showing damage from 1 - 25%, 2 = showing damage from 26 - 50%, 3 = showing damage from 51 - 75%, 4 = showing damage from 76 - 100% as described by Kisetu et al. (2014), Mkenda et al. (2015a) and Mkindi et al. (2017). The data collection started two weeks after the emergence of the crop at the interval of seven (7) days.

3.4.3 Evaluation of the effectiveness of the application of pesticidal plant crude extracts on yield and yield components of bambara groundnut

Five (5) plants were randomly selected from every plot and number of pods plant⁻¹, the number of seeds pod⁻¹ were counted and recorded. After harvesting the entire plot (except plants on the edge of each plot), the weight of 100 seeds, pod yield (kg plot⁻¹) and seeds yield (kg plot⁻¹) was weighed and recorded. The seeds yield (kg ha⁻¹) was measured after drying and threshing then the yield was converted to kg ha⁻¹. The yield and yield components was compared between the treated and the untreated plots.

3.5 Evaluation of the effectiveness of powder of selected pesticidal plants on managing bruchids on bambara groundnuts

3.5.1 Collection and preparation of plant materials

The fresh leaves of B. pilosa, L. camara, T. vogelii, V. amygdalina, L. javanica and T. diversifolia leaves were collected during the dry season around roads and farms in Arusha and Moshi in Tanzania. The pesticidal plants leaves were air-dried under the shade at room temperature (22 °C – 26 °C) and relative humidity (RH) of 75 ± 5% for 14 days. The dry leaves were ground using an electric grinding mill to form the powder which were stored in 10 L plastic containers covered with the airtight-lid in dark condition to avoid degradation of bioactive compounds until when required for subsequent applications (Anjarwalla et al., 2016; Mkenda et al., 2015a).

3.5.2 Collection and rearing bruchids

The stock bruchids used in this study were obtained from infested bambara groundnuts collected from the Singida Municipal Market in Central Tanzania. The insects were reared on untreated bambara groundnut grains kept in plastic buckets of 10 L filled with 5 kg of untreated bambara groundnuts grains. The containers for rearing bruchids were covered with a 1mm mesh to prevent bruchids from escaping from the container. The containers were kept
under room temperature (22 °C – 26 °C) and relative humidity (RH) 75 ± 5% at the Nelson Mandela Institution of Science and Technology (NM-AIST), Tanzania in a storage room.

3.5.3 The experimental setup

The bambara groundnuts grains used in this study were obtained from the Tanzania Agricultural Research Institute (TARI - Naliendele, Mtwara - Tanzania). The bambara grains were cleaned by winnowing and sorted to remove damaged grains. A 1.5 kg of clean, untreated bambara groundnut grains were weighed into cotton storage bags and admixed with powders from *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia* leaves at the rate of 10% (w/w). The positive control, Actellic Dust (Pirimiphos-methyl), Syngenta was applied as per manufacturer’s recommendation while the negative control remained untreated. The experiment was laid out in a randomized complete block design (RCBD) with (6) replications.

3.5.4 Data collection

A grain sample of 150 gm was drawn from each storage bag using a metal grain sampler. The grain was sieved for easy counting of the number of live bruchids, number of dead bruchids, number of damaged seeds, number of seeds with eggs attached on the surface were counted after 30 days’ interval for all treatments for 180 days. After the assessment, the grains, live insects and pesticidal plant powder were returned into the respective containers. The dead bruchids were removed and discarded after every counted to avoid re-counting the same dead insect. The percent insect mortality rate (MR) was calculated as described by Ogendo *et al.* (2003) and Chougourou *et al.* (2016);

\[
MR (\%) = \frac{\text{No. of dead insects}}{\text{Total number of insects}} \times 100 \quad \text{...(i)}
\]

The mortality of insects due to treatments was corrected using Abbott’s correction formula (WHO, 2016).

\[
\text{Corrected mortality (\%)} = \frac{(\text{Observed mortality} - \% \text{Control mortality})}{(100 - \% \text{Control mortality})} \times 100 \quad \text{...(ii)}
\]
3.5.5 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using the STATISTICA 8th edition. The Fisher’s Least Significance Difference (LSD) was used to compare treatment means at $P = 0.05$ level of significance. Microsoft excel software was used to generate graphs.
CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Abundance of arthropod pests on bambara groundnut plants

Figure 8 shows the results of the treatment of the bambara groundnut with the leaf extract of the pesticidal plants (*B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia*), synthetic insecticide (lambda-cyhalothrin 5% EC) as the positive control and untreated plot as the negative control. The results indicate that there was a significant difference between treatments ($P \leq 0.001$) in the abundance of foliage, aphids, mealybugs, red spider mites and leafhoppers, on bambara groundnuts plants. The highest numbers of foliage beetles (0.38 ± 0.051), aphids (0.92 ± 0.084), mealybugs (0.24 ± 0.041 and leafhoppers (2.51 ± 0.148) was observed in untreated plots. Contrary to expectations, red spider mites (0.60 ± 0.093) were observed only in plots treated with synthetic pesticide (Appendix 2). The treatment with the positive control (Karate), *T. vogelii* and *T. diversifolia* were the most effective treatment in the control of the infestation of foliage beetles, aphids, mealybugs and leafhoppers on bambara groundnut plants in the field. Other pesticidal plants leaf extracts were found relatively effective but not as effective as compared with positive control.
4.1.2 Abundance of beneficial arthropods

The results of the treatments with pesticidal plants leaf extracts, synthetic pesticide and untreated plots on the abundance of beneficial arthropods ladybird beetle, hoverfly, wasps and spiders is presented in Fig. 9. The results showed that pesticidal plants had little impact on beneficial arthropods as compared with synthetic pesticide where few beneficial arthropods were observed. The statistical analyses showed that there was a significant difference ($P \leq 0.001$) between the pesticidal plants extracts, negative control and positive control. The higher number of ladybird beetles (0.33 ± 0.046) and hoverflies (0.39 ± 0.057) were observed in untreated plots whereas, the higher number of spiders (0.18 ± 0.029) were observed in plots treated with $L. \text{camara}$ leaf extracts and the higher number of parasitic wasps (0.13 ± 0.03) were observed in plots treated $B. \text{pilosa}$. The least number of beneficial arthropods were observed in pots treated with synthetic pesticide (0.04 ± 0.021, 0.09 ± 0.021, 0.02 ± 0.010 and 0.05 ± 0.016 for ladybird beetle hoverfly, spiders and wasps respectively (Appendix 3).

![Figure 9: Abundance of beneficial arthropods](image)

4.1.3 Incidences and damage severity of different in arthropods damage on bambara groundnuts

Plates 8, 9 and 10 shows the bambara groundnut plants damaged by foliage beetles, aphids and red spider mites respectively. Figure 10 and Fig. 11 respectively represent the pest’s incidence (%) and plant damage inflicted by the arthropod pests on bambara groundnut
treated with pesticidal plant extract, synthetic pesticide (karate) and untreated plots. The statistical analysis showed that the effect of the treatments was significantly different ($P \leq 0.001$) on the incidence and plant damage respectively. Among all pesticidal plants, *T. vogelii* and *T. diversifolia* were the most effective pesticidal plant in preventing the infestation and damage of the plants by the pests. Generally, the highest pest’s incidence (%) and plant damage were recorded in untreated plots. The higher proportions of the plants infested with foliage beetles (20.00 ± 3.428), aphids (31.67 ± 3.722), mealybugs (11.67 ± 3.055) and leafhoppers (56.67 ± 5.667) were observed in untreated plots whereby the higher proportion of the plants infested with spider mites (11.67 ±4.179) (Appendix 4) were observed in plots treated with synthetic insecticide (karate). The higher proportion of the plants was infested by leafhoppers as compared with other pests. The plants damage followed the similar trend for foliage beetles (0.25 ± 0.032), aphids (0.61 ± 0.059), mealybugs (0.15 ± 0.025) and leafhoppers (1.07 ± 0.064) observed in untreated plots and red spider mites (0.51 ± 0.076) was observed in plots sprayed with karate (Appendix 5).

![Figure 10: Percentage of bambara groundnut plants infested by key pest species](image-url)
Plate 8: Bambara plant damaged by foliage beetles

Figure 11: Bambara groundnut plants damage by key pests.
Plate 8: Bambara plant damaged by aphids

Plate 9: Bambara groundnut plant damaged by red spider mites
4.1.4  Yield and yield components of bambara groundnut

Figure 12 shows the results of the treatment of the bambara groundnut with pesticidal plants, karate (positive control) and untreated plots. The results indicate that there was a significant difference ($P \leq 0.001$) in the number of pods plant$^{-1}$, the number of seeds plant$^{-1}$ and the weight of seeds (100 seeds weight). There was no significant difference in pod yield (kg ha$^{-1}$), seeds yield (kg ha$^{-1}$) across the treatments. However, the highest number of pods per plant was recorded in plots treated with *L. camara* (16.25 ± 0.854) whereby the lowest number of pods per plant was observed in negative control plots. The plots treated with *L. javanica* displayed the highest number of seeds pod$^{-1}$ (1.17 ± 0.049) whereas; the lowest number of seeds per pod was observed in plots treated with *B. pilosa* (1.05 ± 0.020). Moreover, the highest weight of seeds (100 seeds weight) was observed in plots treated with *T. diversifolia* (39.90 ± 2.327) whereas; on the other hand, the least weight of 100 seeds was observed in plots treated with *L. javanica* (28.85 ± 2.156). The highest pod yield (kg ha$^{-1}$) (493.25 ± 86.765) was observed in in plots treated with *T. diversifolia* whereas, highest seeds yield (kg ha$^{-1}$) (289.35 ± 36.938) were observed in both plots treated with *T. diversifolia* and *T. vogelii* (Appendix 6).

![Figure 12: Bambara groundnut pod yield (kg ha$^{-1}$)](image)

4.1.5  Live *C. maculatus* on bambara groundnuts

The results of the effectiveness of the pesticidal plant powders are presented in Table 2. The findings from this study revealed that all pesticidal plants powder significantly reduced the number of live *C. maculatus* in the bags throughout the storage period ($P \leq 0.001$). The
untreated bags (negative control) generally contained the highest number of live bruchids (5.00 ± 1.069, 10.71 ± 1.209, 27.57 ± 1.172, 61.00 ± 4.593) for 30, 60, 90 and 120 days; respectively. For 150 and 180 days, the highest numbers of live insects were observed on bags treated with *T. diversifolia* and *C. dichogamus*. *Tephrosia vogelii* dry leaf powder demonstrated very high effectiveness in preventing the infestation and emergence of bruchids in a similar way as the positive control (actellic dust). Pesticidal plants powder; *B. pilosa, L. camara, V. amygdalina, L. javanica* and *C. dichogamus* showed varying effectiveness against the infestation of *C. maculatus* on bambara groundnut seeds. The number of live insects generally increased from 30 - 120 days for all treatments. The trend of increase of live insects was maintained for the seeds treated with actellic dust, *T. vogelii, T. diversifolia* and *C. dichogamus*. However, for the bags treated with *B. pilosa, L. camara, V. amygdalina and L. javanica* the number of live bruchids progressively decreased from 150 - 180 days.
Table 2: Mean number of live insects (*C. maculatus*) in stored bambara groundnuts

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Mean ± SE of live <em>C. maculatus</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 days</td>
</tr>
<tr>
<td><em>B. pilosa</em></td>
<td>1.83 ± 0.601b</td>
</tr>
<tr>
<td><em>L. camara</em></td>
<td>1.67 ± 0.558b</td>
</tr>
<tr>
<td><em>V. amygdalina</em></td>
<td>1.33 ± 0.558bc</td>
</tr>
<tr>
<td><em>T. diversifolia</em></td>
<td>0.50 ± 0.342bc</td>
</tr>
<tr>
<td><em>T. vogelii</em></td>
<td>0.00 ± 0.000c</td>
</tr>
<tr>
<td><em>L. javanica</em></td>
<td>0.83 ± 0.307bc</td>
</tr>
<tr>
<td><em>C. dichogamus</em></td>
<td>0.33 ± 0.211bc</td>
</tr>
<tr>
<td>Actellic Dust</td>
<td>0.00 ± 0.000c</td>
</tr>
<tr>
<td>Negative Control</td>
<td>5.00 ± 1.069a</td>
</tr>
</tbody>
</table>

One-way ANOVA

| F-statistic | 9.04*** | 24.34*** | 14.05*** | 29.82*** | 3.80** | 9.71** |

***, ** significant at *P* ≤ 0.05 and *P* ≤ 0.001 respectively. Means within the same column followed by the same letter(s) are not significantly different at (*P* = 0.05) using Fisher’s Least Significant Difference (LSD) test.
4.1.6 Mortality of *C. maculatus*

Table 3 shows the mortality of *C. maculatus* in bambara groundnuts seeds treated with dry powder from leaves of *B. pilosa, L. camara, V. amygdalina, T. diversifolia, T. vogelii, L. javanica, C. dichogamus*, positive control (Actellic dust) and negative control. Among all treatments *T. vogelii* and actellic dust were the most effective treatments by killing 93.07 - 100% and 91.33 - 100% of bruchids respectively for 180 days of the study (Fig. 13). All treatments showed significant (*P* ≤ 0.001) effect on bruchids mortality. The dead insects were recorded for both insects inside the bags and those killed on the surface of the bags. For *T. vogelii* and actellic dust, most of the dead insects were observed on the surface on the storage bags. Other pesticidal plants displayed varying bruchids mortality but not as higher as the mortality caused by Actellic Dust and *T. vogelii*. For all treatments, the number of dead increased with exposure time from 30 – 180 days.

![Figure 13: Percent corrected mortality of *C. maculatus*](image)

*Figure 13: Percent corrected mortality of *C. maculatus*
Table 3: Mean number of dead insects (*C. maculatus*) in stored bambara groundnuts

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Mean ± SE of dead <em>C. maculatus</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 days</td>
</tr>
<tr>
<td><em>B. pilosa</em></td>
<td>0.17 ± 0.167b</td>
</tr>
<tr>
<td><em>L. camara</em></td>
<td>0.00 ± 0.000b</td>
</tr>
<tr>
<td><em>V. amygdalina</em></td>
<td>0.33 ± 0.333b</td>
</tr>
<tr>
<td><em>T. diversifolia</em></td>
<td>0.00 ± 0.000b</td>
</tr>
<tr>
<td><em>T. vogelii</em></td>
<td>2.17 ± 0.307a</td>
</tr>
<tr>
<td><em>L. javanica</em></td>
<td>0.50 ± 0.342b</td>
</tr>
<tr>
<td><em>C. dichogamus</em></td>
<td>1.83 ± 0.980a</td>
</tr>
<tr>
<td>Actellic Dust</td>
<td>2.29 ± 0.680a</td>
</tr>
<tr>
<td>Negative Control</td>
<td>0.00 ± 0.000b</td>
</tr>
</tbody>
</table>

One-way ANOVA

- **F-statistic**: 4.94***, 5.94***, 8.66***, 33.47***, 28.22***, 20.06***

*** Significant at *P* ≤ 0.001. Means within the same column followed by the same letter(s) are not significantly different at (*P* = 0.05) using Fisher’s Least Significant Difference (LSD) test.
4.1.7 Bambara groundnut grains damage by *C. maculatus*

The results of the treatment of the bambara groundnut seeds with the dry powder from *B. pilosa, L. camara, V. amygdalina, T. diversifolia, T. vogelii, L. javanica, C. dichogamus* and synthetic pesticide on the seeds damage is presented in Table 4. The results of this study showed that the treatment of the bambara groundnuts with pesticidal plants powder significantly protected the bambara groundnut seeds against damage by *C. maculatus* among treatments throughout the study period (*P* ≤ 0.001). The highest damage was observed in the untreated bags (9.57 ± 2.125, 50.43 ± 9.149, 115.86 ± 9.290 and 286.14 ± 39.178, 419.86 ± 26.516 and 448.14 ± 20.249) for 30, 60, 90, 120, 150 and 180 days of assessment; respectively. The treatment with *T. vogelii* leaf powder and synthetic pesticide showed high effectiveness in protecting the bambara groundnut seeds damage by *C. maculatus* followed by *C. dichogamus* and *T. diversifolia*. Other pesticidal plants leaf powder, *L. javanica, B. pilosa, L. camara* and *V. amygdalina* showed relatively lower efficacy in protecting the bambara groundnut seeds against damage by *C. maculatus*. For all treatments, the damage increased with time from 30 - 180 days of storage. The increase in the number of seeds damaged from 30 - 180 days may be due to the increase of the live bruchids with time which is a result of degradation of active ingredients in pesticidal plants with time.
Table 4: Mean number of damaged bambara groundnut seeds

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean ± SE of damaged bambara groundnut</th>
<th>30 days</th>
<th>60 days</th>
<th>90 days</th>
<th>120 days</th>
<th>150 days</th>
<th>180 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. pilosa</td>
<td></td>
<td>6.67 ± 2.140a</td>
<td>41.83 ± 2.496ab</td>
<td>86.17 ± 5.282b</td>
<td>248.50 ± 7.464ab</td>
<td>329.00 ± 17.047b</td>
<td>381.67 ± 17.990ab</td>
</tr>
<tr>
<td>L. camara</td>
<td></td>
<td>3.00 ± 1.033b</td>
<td>33.17 ± 5.388b</td>
<td>71.67 ± 8.349b</td>
<td>236.67 ± 13.111ab</td>
<td>292.83 ± 24.510b</td>
<td>381.83 ± 13.465ab</td>
</tr>
<tr>
<td>V. amygdalina</td>
<td></td>
<td>2.67 ± 0.989b</td>
<td>31.17 ± 1.887b</td>
<td>68.17 ± 8.491b</td>
<td>203.83 ± 14.646b</td>
<td>273.50 ± 8.962bc</td>
<td>344.83 ± 13.683b</td>
</tr>
<tr>
<td>T. diversifolia</td>
<td></td>
<td>1.33 ± 0.715b</td>
<td>11.33 ± 2.140cd</td>
<td>40.67 ± 3.648de</td>
<td>125.83 ± 6.544ef</td>
<td>204.00 ± 12.649d</td>
<td>272.83 ± 14.965cd</td>
</tr>
<tr>
<td>T. vogelii</td>
<td></td>
<td>0.00 ± 0.000b</td>
<td>0.00 ± 0.000d</td>
<td>0.00 ± 0.000g</td>
<td>1.17 ± 0.477g</td>
<td>5.50 ± 0.957f</td>
<td>10.50 ± 2.778f</td>
</tr>
<tr>
<td>L. javanica</td>
<td></td>
<td>1.83 ± 0.543b</td>
<td>15.50 ± 3.403c</td>
<td>51.00 ± 7.253de</td>
<td>173.00 ± 14.093de</td>
<td>215.83 ± 19.734cd</td>
<td>327.50 ± 24.930bc</td>
</tr>
<tr>
<td>C. dichogamus</td>
<td></td>
<td>0.50 ± 0.342b</td>
<td>2.17 ± 0.601d</td>
<td>24.00 ± 4.163ef</td>
<td>89.67 ± 14.523ef</td>
<td>155.83 ± 30.869d</td>
<td>252.67 ± 27.742d</td>
</tr>
<tr>
<td>Actellic dust</td>
<td></td>
<td>0.00 ± 0.000b</td>
<td>0.14 ± 0.143d</td>
<td>8.43 ± 5.639fg</td>
<td>46.14 ± 25.682fg</td>
<td>69.86 ± 29.278e</td>
<td>142.29 ± 44.029e</td>
</tr>
<tr>
<td>Negative Control</td>
<td></td>
<td>9.57 ± 2.125a</td>
<td>50.43 ± 9.149a</td>
<td>115.86 ± 9.290a</td>
<td>286.14 ± 39.178a</td>
<td>419.86 ± 26.516a</td>
<td>448.14 ± 20.249a</td>
</tr>
</tbody>
</table>

One-way ANOVA

F-statistic 7.94*** 21.26*** 34.85*** 23.92*** 36.15*** 32.60***

*** significant at $P \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher’s Least Significant Difference (LSD) test.
4.1.8 Oviposition of *C. maculatus* on bambara groundnut seeds

Treatment with pesticidal plants dry leaf powder showed varied effectiveness on oviposition of *C. maculatus* on the bambara groundnut seeds surface for 180 days of the study. The results showed that there was a significant difference (*P* ≤ 0.001) in the number of bambara groundnut seeds with eggs on the surface throughout the study period. The highest number of seeds with eggs on the surface was observed in untreated seeds (54.00 ± 10.704, 91.86 ± 13.440, 152.86 ± 14.530, 215.14 ± 26.593, 69.43 ± 13.156 and 38.14 ± 9.130) for 30, 60, 90, 120, 150 and 180 days respectively (Table 5). The lowest number of seeds with eggs on the surface were observed on the seeds treated with *T. vogelii* and actellic dust. For the first 30 days of the storage *T. vogelii* and actellic dust completely prevented the oviposition of the *C. maculatus* on bambara groundnut seeds whereby, from the 90-180 day of assessment few seeds with eggs on the surface were observed on seeds treated with the *T. vogelii* and synthetic pesticide (actellic dust). The dry leaf powder from other pesticidal plants powder (*B. pilosa, L. camara, V. amygdalina, T. diversifolia, L. javanica* and *C. dichogamus*) showed varied effectiveness in preventing the oviposition of *C. maculatus* on bambara groundnut seeds. There is generally decrease in number of seeds with the eggs on the surface from 150 - 180 days for bags treated with *B. pilosa, L. camara, V. amygdalina, T. diversifolia, L. javanica* and *C. dichogamus* leaf powders.
Table 5: Mean number of bambara groundnut seeds with eggs on the surface

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean ± SE of bambara groundnut seeds with eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 days</td>
</tr>
<tr>
<td>L. camara</td>
<td>10.17 ± 3.506b</td>
</tr>
<tr>
<td>V. amygdalina</td>
<td>10.33 ± 2.333b</td>
</tr>
<tr>
<td>T. diversifolia</td>
<td>4.33 ± 1.453b</td>
</tr>
<tr>
<td>T. vogelii</td>
<td>0.00 ± 0.000b</td>
</tr>
<tr>
<td>L. javanica</td>
<td>9.33 ± 3.480b</td>
</tr>
<tr>
<td>C. dichogamus</td>
<td>3.33 ± 1.116b</td>
</tr>
<tr>
<td>Actellic Dust</td>
<td>0.00 ± 0.000b</td>
</tr>
<tr>
<td>Negative Control</td>
<td>54.00 ± 10.704a</td>
</tr>
</tbody>
</table>

One-way ANOVA


***, ** significant at $P \leq 0.05$ and $P \leq 0.001$ respectively. Means within the same column followed by the same letter(s) are not significantly different at $(P = 0.05)$ using Fisher’s Least Significant Difference (LSD) test.
4.2 Discussion

4.2.1 Effectiveness of pesticidal plant extracts on field pests in bambara groundnuts.

The results of present study have showed that the leaf extracts of *B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *T. vogelii* and *L. javanica* were effective against foliage beetles (*O. spp.*) (Coleoptera: Chrysomelidae), aphids (*Aphis spp.*) (Hemiptera: Aphididae), mealybugs (Hemiptera: Pseudococcidae), red spider mites (*Tetranychus sp.* (Acari: Tetranychidae) and leafhoppers, (Homoptera: Cicadellidae) on bambara groundnuts. The pesticidal plants tested in this study exhibited pesticidal efficacy against all the tested insects. The insecticidal activity of the pesticidal plants is a result of the bioactive compounds that either deter feeding of the pests, kill the pests or repel pests from landing on plants for feeding or inhibit the insect's development (Belmain *et al.*, 2013; Isman, 2000). The findings of this study are in line with the findings from the previous studies (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Tembo *et al.*, 2018) with regard to the effectiveness of pesticidal plant extract against pests.

From the findings of the present study, it was revealed that *T. vogelii* was most effective among all the pesticidal plants evaluated. It highly reduced the abundance of arthropod pests and ultimately lowered the damage of the bambara groundnuts against field pests. The efficacy of *T. vogelii* against pests is a result of the presence of rotenoids which have been reported to have insecticidal properties (Belmain *et al.*, 2012; Mkindi *et al.*, 2019). The findings of this study is supported by the previous studies involving the use of extracts from *T. vogelii* foliar parts against foliage beetles (*O. mutabilis* and *O. bennigseni*), flower beetles (*Epicauta albovittata* and *E. limbatipennis*), aphids (*Aphis fabae*) and pod suckers (*Clavigralla tomentosicollis* and *C. hystricodes*) (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Tembo *et al.*, 2018).

Interestingly, the current study found that the extracts from *T. diversifolia* leaves showed pesticidal activity against foliage beetles, aphids, mealybugs, leafhoppers and red spider mites in the bambara groundnuts. The pesticidal activity of *T. diversifolia* leaf extracts is in partly explained by the presence of sesquiterpene lactones that have insecticidal properties (Green *et al.*, 2017). Previous research with regard to the use of extracts of *T. diversifolia* also reported the promising results against insect pests of common beans (Mkenda *et al.*, 2015a; Mkindi *et al.*, 2017; Tembo *et al.*, 2018). *Lantana camara* leaves extracts are rich in
sesquiterpenes including α-humelene and cis-caryophyllene which have anti-insects properties (Sohani et al., 2012). The results of this study showed that the extracts from *L. camara* was capable to reduce infestation of the arthropod pests on bambara groundnuts. The finding of the present study is in line with previous findings by (Mkindi et al., 2017) when the leaf extracts were evaluated against the common bean insect pests. The pesticidal activity of *L. camara* is attributed by presence of bioactive compounds such as pentacyclic triterpenoids (Patel, 2011). The insecticidal activity of *V. amygdalina* is in part explained by presence of phytochemicals such as sesquiterpene lactones (vernodalinel and vernodalol) and flavonoids such as luteolin, luteolin 7-O-glucosides and luteolin 7-O-glucuronide, steroid glycosides, and vernonioside which were previously reported to have insect antifeedant, antitumoral, antifungal, and cytotoxic activity (Erasto et al., 2006; Farombi & Owoeye, 2011; Green et al., 2017). The results of the current study are supported by the previous research findings on the insecticidal property of the *V. amygdalina*. Furthermore, in the current study, *L. javanica* significantly reduced pest’s abundance and hence the bambara groundnut plants damage. The insecticidal activity of *L. javanica* is in part explained by the presence of camphor and is also previously reported to have activity against insect pests (Mkenda et al., 2015a). The fact that there was no infestation of red spider mites observed in plots treated with pesticidal plants including *L. javanica* provided proof that pesticidal plants contain diverse bioactive compounds that have acaricidal activity as previously reported in *L. javanica* (Madzimure et al., 2011). *Bidens pilosa* is another pesticidal plant that has provided significant reduction in the pest’s infestation on bambara groundnuts. *Bidens pilosa* contain sesquiterpenes germacrene-D and β-caryophyllene and τ-cadinene that might have attributed to the plants pesticidal potential.

With respect to beneficial arthropods, the current study revealed that pesticidal plants treatments have lower detrimental effect on beneficial arthropods; ladybird beetle (*Coccinella magnifica*) (Coleoptera: Coccinellidae), hoverfly (Diptera: Syrphidae), wasps (Hymenoptera) and spiders (Araneae) as compared with synthetic pesticide. The higher abundance of beneficial arthropods observed in plots treated with pesticidal plants and untreated plots is explained partly by less threat of pesticidal plants extracts on non-target organisms (Mkindi et al., 2017). On the other hand, a very lower abundance of beneficial arthropods was observed in plots treated with synthetic pesticide (positive control). This is in part due to the high lethal effect of synthetic pesticides and persistence unlike pesticidal plants (Ndakidemi et al., 2016). Pesticidal plants pose low lethal effects due to the presence of less concentration
of active ingredients (Desneux et al., 2007). The active ingredients from pesticidal plants have a short life span in the environment and the soil as result over time they eventually lose their qualities such as odor, color, flavor and consistency (Miresmailli & Isman, 2014). Low persistence in the plants and soil after application makes it only effectively deter pests from feeding for shorter duration unlike synthetic pesticides which are highly persistent after application (Miresmailli & Isman, 2014). This even necessitates frequent application unlike synthetic pesticides. However, the lower persistence and lower lethal effect help the buildup of the population of natural enemies that also helps to provide the ecosystem services by feeding of the pests (Desneux et al., 2007).

In terms of yield and yield components of bambara groundnuts, the findings of the present study showed a higher number of pods/plant in plots treated with *L. camara* leaf extracts and a higher number of seeds per pod in plots treated with *L. javanica* leaf extracts. The highest 100 seeds weight was observed in plots treated with *T. diversifolia* leaf extracts. There was no significant difference in terms of the pod and seed yield (kg/ha). Moreover, there was no significant difference in terms of the pod and seed yield (kg/ha). However, the higher pod yield and seeds yield (kg/ha) was observed in plots treated with *T. diversifolia* and *T. vogelii* leaf extracts. This could be explained in part by higher efficacy of the two plants in reducing the infestation of pests and hence lower plants damage and higher nitrogen content that might have provided additional nitrogen in form of foliar application (Jama et al., 2000). The findings of this study are in line with the findings from studies by Mkindi et al. (2020). In their study, the extracts from *T. diversifolia* and *T. vogelii* were found to boost the chlorophyll content and enhanced the growth and yield of the common beans. Contrary to expectations, the positive control (synthetic pesticide) had lower yield when compared with the pesticidal plant treatments and negative control. This might have been facilitated by heavy damage of the bambara groundnut plants due to the high infestation of red spider mites (*Tetrunychus sp.* (Acari: Tetranychidae) observed in plots treated with synthetic pesticide (karate). However, the yield obtained from this trial is generally lower than the average potential yield of 1 500–2 000 kg ha\(^{-1}\) (NARI, 2015). The lower average yield of the crop might be due to unfavorable climatic conditions including lower rains in the 2019 cropping season in Arusha, Tanzania which affected the yield of the crop.
4.2.2 Effectiveness of selected pesticidal plant leaf powders on the management of bruchids (*C. maculatus*) on bambara groundnuts

In this study, the effectiveness of *B. pilosa*, *L. camara*, *V. amygadalina*, *T. diversifolia*, *T. vogelii*, *L. javanica*, *C. dichogamus* and synthetic pesticide (actellic dust) were evaluated on *C. maculatus* live insects, mortality, bambara groundnut seeds damage (bruchids perforated seeds) and oviposition. The results of the study revealed the treatment of bambara groundnut seeds with dry powder from all pesticidal plant materials showed varied effectiveness as grain protectants against bruchids, *C. maculatus* infestation. The dry powder from the *T. vogelii* leaves was the most effective among all pesticidal plants evaluated displaying few live *C. maculatus*, high insect mortality, low oviposition and low grain damage. The treatment with *T. vogelii* completely protected the *C. maculatus* infestation for the first 90 days of the study. Despite the fact that its effectiveness slightly decreased after 90 days, however, it remained the most effective treatment against *C. maculatus*. The insecticidal activity of *T. vogelii* is in part explained by the presence diverse bioactive chemical compounds including Chemotype 1 (C1) which contains rotenoids with mammalian toxicity required for pest control (*Belmain et al.*, 2012; *Stevenson et al.*, 2012). The slight decrease in effectiveness after 90 days may be due to degradation of active ingredients over time. Other pesticidal plants *B. pilosa*, *L. camara*, *V. amygadalina*, *T. diversifolia*, *C. dichogamus* and *L. javanica* protected the bambara groundnut seeds against infestation and emergence of bruchids but was relatively less effective as compared with *T. vogelii* and positive control. This is indicated by the presence of a relatively higher number of live *C. maculatus*, high bruchids mortality, fewer seeds damage and lower oviposition in the bags in the bags treated with powder from the leaves *T. vogelii*. These findings are in line with the findings of the study conducted by *Ogendo et al.* (2003a) in which the *T. vogelii* leaf powder resulted to the mortality of maize weevil (*S. Zeamais*) in stored maize grain ranging from 85.0 – 93.7%. Their study showed that, the mortality of bruchids is proportional to the exposure time. Similar findings were obtained by *Koona and Dorn* (2005) when they investigated the potential of extracts from *T. vogelii* for the control of bruchids on stored legumes.

The results of the present study showed that *C. dichogamus* has insecticidal activity against *C. maculatus*. The treatment with the leaf powder from *C. dichogamus* displayed insect mortality, lower grain damage, few seeds with eggs on the surface and few live insects. The insecticidal property of *C. dichogamus* may be due to the presence of diverse toxic bioactive
compounds such as crotofolane, diterpenoids, crotoxide A and B previously isolated from C. dichogamus leaves (Jogia et al., 1989).

The insecticidal activity of T. diversifolia could be in part explained by presence of chemical compounds such as sesquiterpene lactones tagitin A, tagitin B, tagitin C, tagitin D and tagitin H which have shown insecticidal activities against C. maculatus (Green et al., 2017). Lippia javanica leaf powder on the other hand showed a significant effect on bruchids, grain damage, oviposition deterrent and bruchids mortality. The killing ability of L. javanica is attributed by chemical compounds such as camphor as the major component and other minor components such as camphene, α-pinene, eucalyptol, Z and E α-terpineol, linalool, cymene, thymol, 2-carene, caryophyllene and α-cubebene (Mkenda et al., 2015b). The camphor a monoterpenoid is reported to have insecticidal potential (Chen et al., 2018; Gillij et al., 2008; Mkenda et al., 2015b; Singh et al., 2014; Tembo et al., 2018). The findings of this study are in line with the findings of research by Chikukura et al. (2011) in which the leaf powders demonstrated insecticidal potential against storage insect pests of maize and cowpeas including S. zeamais, C. maculatus, Prostephanus truncates, Tribolium spp and Sitotroga cerealella.

Moreover, the treatment of bambara groundnut seeds with V. amygdalina leaf powder also resulted to lower the number of adult bruchids, lower seeds damage, lower oviposition and insect mortality as compared with the negative control. The insecticidal activity of the plant is attributed by presence of bioactive compounds such as sesquiterpene lactones including the vernolide and vernodalol (Erasto et al., 2006; Igile et al., 1994), flavonoids such as luteolin, luteolin 7-O-glucosides and luteolin 7-O-glucuronide, steroid glycosides, and vernonioside A, B, A1, A2, A3, B2, B3 and A4 (Farombi & Owoeye, 2011; Igile et al., 1994). Several studies have reported the insecticidal potential of leaf powders of V. amygdalina against C. maculatus (F.) (Akunne et al., 2014), beans weevil (A. obtectus) (Adeniyi et al., 2010) and maize weevil (S. zeamais) (Asawalam & Hassanali, 2006).

The results showed that L. camara has a potential effect in protecting bambara groundnuts against C. maculatus damage. The treatment with the powder from L. camara leaves often showed a higher number of live insects, the number of seeds with eggs, low insect mortality and higher grains damage comparing with T. vogelii and positive control but performed better as compared with the negative control. The insecticidal activity of L. camara is influenced by the presence of pentacyclic triterpenoids (Durbesula et al., 2015). The L. camara extracts are
reported to have fumigant and contact toxicity against storage insects, *S. oryzae* (L.) *C. chinensis* (Fab.) and *Tribolium castaneum* (Herbst.) (Rajashekar *et al*., 2014). Other studies by Ogendo *et al.* (2003a) revealed the insecticidal potential of leaf powder from *L. camara* against maize weevil. It was found that after 21 days, *L. camara* at the rate of 7.5-10% (w/v) resulted in 82.7% insect mortality.

Furthermore, the treatment with *B. pilosa* leaf powder displayed significant impact on protecting bambara groundnut against damage by *C. maculatus*. This is indicated by presence of relatively few live insects, low grain damage, low oviposition and high insect mortality as compared with untreated seeds. The insecticidal activity of *B. pilosa* might be explained in part by the presence of bioactive compounds such as sesquiterpenes germacrene-D and β-caryophyllene and τ-cadinene previously isolated from the flowers and leaves (Deba *et al*., 2008; Lima Silva *et al*., 2011). Previous studies by Goudoum *et al.* (2016) revealed the anti-insect function of the plant. It was found the essential oils from the leaves have insecticidal action against bruchids (*C. maculatus*). Renuka *et al.* (2014) investigated the essential oils from the leaves of *B. pilosa* investigated the methanol and acetone extracts of *B. pilosa* against stored pests of kidney beans, the *Z. subfasciatus* (Boheman) and *A. obtectus* (Say) (Coleoptera: Chrysomelidae). Both acetone and methanol extracts were found to cause 100% mortality of *A. obtectus* and *Z. subfasciatus*. For all treatments, there was continuous increase of the number of seeds damaged for all treatments from 30-120 days of the storage. However, *T. vogelii* leaf powder maintained its very high effectiveness throughout the study period. The increase of the damaged number of the bambara groundnut seeds was partly due to the increase in the number of live *C. maculatus* which may be due to degradation of the bioactive compounds in pesticidal plants over time. Additionally, the killing ability displayed by all pesticidal plants powders used this study could be partly explained by the presence of bioactive compounds aided by the action of fine powder blocking the insect spiracles resulting to death due to suffocation (Obembe & Kayode, 2013).
5.1 Conclusion

In conclusion, the findings of the present study showed that pesticidal plants are effective in controlling the field pests and the storage insect (*C. maculatus*) in bambara groundnuts. Under field conditions, it was found that the pesticidal plants extracts of *B. pilosa*, *L. camara*, *T. vogelii*, *V. amygdalina*, *L. javanica* and *T. diversifolia* at the concentration of 10% (w/v) are effective for controlling the field pests including foliage beetles (*O. spp.*), aphids (*Aphis spp.*), mealybugs, red spider mites (*Tetrunychus sp.*.) and leafhoppers. Interestingly, *T. vogelii* was the most effective pesticidal plants extracts against field pests and *C. maculatus* of bambara groundnuts among all pesticidal plants investigated. From the field experiment, it was found that the treatments with pesticidal plants (*B. pilosa*, *L. camara*, *V. amygdalina*, *T. diversifolia*, *T. vogelii*, *L. javanica*) can control pests in the field without potential threat to the beneficial arthropods that can regulate the abundance of the pests. The treatment with pesticidal plants besides controlling pests and enhancing the abundance of beneficial arthropods, they also improved the yield of the bambara groundnuts. This indicates that the application of pesticidal plants specifically leguminous species (*T. vogelii*) and *T. diversifolia* (Asteraceae) supplements additional nutrients to the plants in the form of foliar applications. In a storage experiment, *T. vogelii* 10% (w/w) was the most effective among other pesticidal plants powder. This is indicated by their ability to reduce the infestation of bruchids, seeds damage (perforation), oviposition and cause higher insect mortality as compared with other pesticidal plants powders. This entails that, the pesticidal plants powder are effective grain protectant.

5.2 Recommendations

The findings of this study have indicated that pesticidal plants extracts are effective in controlling of bambara groundnuts pests in the field and post-harvest pests. Therefore, this study recommends:

(i) The use of *T. vogelii* extract for control field pests and dry leaf powder for control of storage insects in bambara groundnuts.
(ii) Future research to determine the level of toxicity on the non-target organism and possible health risks associated with the use of botanical pesticides including consumption of the crop produce protected by the use of pesticidal plants extract and powders.

(iii) The study suggests determining the shelf-life of the bioactive compounds in pesticidal plants under field conditions to optimize the proper application intervals without the pesticidal plants losing their quality to protect the crops against pests.

(iv) Future research to determine the amount of mineral nutrients added by foliar application of *T. diversifolia* and *T. vogelii*.

(v) Currently, most of these plants are harvested from the wild without proper sustainable replanting by the farmers. This study recommends developing strategies that promote the conservation of pesticidal plants which have shown high effectiveness for the sustainable availability of these plants.

(vi) The findings of this study revealed that plots treated with synthetic pesticides (and not other treatment) were infested by red spider mites contrary to expectations. Thus future research is recommended to evaluate the influence of the synthetic pesticide on red spider mite infestation.
REFERENCES


APPENDICES

Appendix 1: Plot layout in RCBD

<table>
<thead>
<tr>
<th>R-I</th>
<th>R-II</th>
<th>R-IV</th>
<th>R-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP</td>
<td>VA</td>
<td>TV</td>
<td>LJ</td>
</tr>
<tr>
<td>LC</td>
<td>KT</td>
<td>VA</td>
<td>BP</td>
</tr>
<tr>
<td>TV</td>
<td>TD</td>
<td>UT</td>
<td>KT</td>
</tr>
<tr>
<td>VA</td>
<td>BP</td>
<td>LC</td>
<td>TD</td>
</tr>
<tr>
<td>LJ</td>
<td>UT</td>
<td>KT</td>
<td>TV</td>
</tr>
<tr>
<td>TD</td>
<td>LC</td>
<td>LJ</td>
<td>UT</td>
</tr>
<tr>
<td>KT</td>
<td>TV</td>
<td>BP</td>
<td>VA</td>
</tr>
<tr>
<td>UT</td>
<td>LJ</td>
<td>TD</td>
<td>LC</td>
</tr>
</tbody>
</table>

KEY

R. I-IV: Replications
BP: *Bidens pilosa*
LC: *Lantana camara*
VA: *Vernonia amygdalina*
TV: *Tephrosia vogelii*
TD: *Tithonia diversifolia*
LJ: *Lippia javanica*
KT: Karate (Lambda-cyhalothrin)
UT: Untreated
## Appendix 2: Arthropod pest abundance

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Foliage beetles</th>
<th>Aphids</th>
<th>Spider mites</th>
<th>Mealybugs</th>
<th>Leafhoppers</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. pilosa</td>
<td>0.11 ± 0.023bcd</td>
<td>0.47 ± 0.061b</td>
<td>0.00 ± 0.000b</td>
<td>0.08 ± 0.021bc</td>
<td>1.53 ± 0.112b</td>
</tr>
<tr>
<td>L. camara</td>
<td>0.13 ± 0.029b</td>
<td>0.39 ± 0.055b</td>
<td>0.00 ± 0.000b</td>
<td>0.09 ± 0.023bc</td>
<td>1.69 ± 0.119b</td>
</tr>
<tr>
<td>V. amygdalina</td>
<td>0.13 ± 0.028b</td>
<td>0.40 ± 0.054b</td>
<td>0.00 ± 0.000b</td>
<td>0.12 ± 0.027b</td>
<td>1.74 ± 0.123b</td>
</tr>
<tr>
<td>T. diversifolia</td>
<td>0.05 ± 0.015cde</td>
<td>0.18 ± 0.031c</td>
<td>0.00 ± 0.000b</td>
<td>0.05 ± 0.014c</td>
<td>1.01 ± 0.093c</td>
</tr>
<tr>
<td>T. vogelii</td>
<td>0.04 ± 0.012de</td>
<td>0.15 ± 0.030c</td>
<td>0.00 ± 0.000b</td>
<td>0.03 ± 0.013cd</td>
<td>1.13 ± 0.098c</td>
</tr>
<tr>
<td>L. javanica</td>
<td>0.12 ± 0.025bc</td>
<td>0.34 ± 0.049b</td>
<td>0.00 ± 0.000b</td>
<td>0.12 ± 0.028b</td>
<td>1.54 ± 0.115b</td>
</tr>
<tr>
<td>Karate</td>
<td>0.02 ± 0.008e</td>
<td>0.00 ± 0.003d</td>
<td>0.60 ± 0.093a</td>
<td>0.01 ± 0.008d</td>
<td>0.14 ± 0.037d</td>
</tr>
<tr>
<td>Negative</td>
<td>0.38 ± 0.051a</td>
<td>0.92 ± 0.084a</td>
<td>0.00 ± 0.000b</td>
<td>0.24 ± 0.041a</td>
<td>2.51 ± 0.148a</td>
</tr>
</tbody>
</table>

### One-way ANOVA

| F-statistic | 17.72*** | 28.76*** | 41.83*** | 8.58*** | 38.77*** |

*** significant at $P \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at $(P = 0.05)$ using Fisher’s Least Significant Difference (LSD) test.
### Appendix 3: Beneficial arthropods abundance

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Lady bird beetle</th>
<th>Hoverfly</th>
<th>Spiders</th>
<th>Wasps</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. pilosa</td>
<td>0.19 ± 0.032b</td>
<td>0.29 ± 0.048a</td>
<td>0.15 ± 0.027a</td>
<td>0.13 ± 0.028b</td>
</tr>
<tr>
<td>L. camara</td>
<td>0.23 ± 0.043ab</td>
<td>0.35 ± 0.055a</td>
<td>0.18 ± 0.029a</td>
<td>0.11 ± 0.024ab</td>
</tr>
<tr>
<td>V. amygdalina</td>
<td>0.23 ± 0.049ab</td>
<td>0.33 ± 0.051a</td>
<td>0.16 ± 0.030a</td>
<td>0.11 ± 0.025ab</td>
</tr>
<tr>
<td>T. diversifolia</td>
<td>0.28 ± 0.074ab</td>
<td>0.28 ± 0.044a</td>
<td>0.11 ± 0.022a</td>
<td>0.07 ± 0.020bc</td>
</tr>
<tr>
<td>T. vogelii</td>
<td>0.24 ± 0.048ab</td>
<td>0.27 ± 0.047a</td>
<td>0.13 ± 0.024a</td>
<td>0.06 ± 0.016bc</td>
</tr>
<tr>
<td>L. javanica</td>
<td>0.28 ± 0.045ab</td>
<td>0.31 ± 0.050a</td>
<td>0.14 ± 0.023a</td>
<td>0.08 ± 0.021abc</td>
</tr>
<tr>
<td>Karate</td>
<td>0.04 ± 0.021c</td>
<td>0.09 ± 0.021b</td>
<td>0.02 ± 0.010b</td>
<td>0.05 ± 0.016c</td>
</tr>
<tr>
<td>Negative</td>
<td>0.33 ± 0.046a</td>
<td>0.39 ± 0.057a</td>
<td>0.14 ± 0.023a</td>
<td>0.12 ± 0.024ab</td>
</tr>
</tbody>
</table>

**One-way ANOVA**

| F-statistic | 3.37*** | 3.46*** | 3.65*** | 2.00* |

*; *** significant at $P \leq 0.05$ and $P \leq 0.001$ respectively. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher’s Least Significant Difference (LSD) test
### Appendix 4: Pests incidence (%)

#### Arthropod Pests incidence (%)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Foliage beetles</th>
<th>Aphids</th>
<th>Spider mites</th>
<th>Mealybugs</th>
<th>Leafhoppers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B. pilosa</strong></td>
<td>8.33 ± 2.194bc</td>
<td>20.33 ± 3.062b</td>
<td>0.00 ± 0.000b</td>
<td>6.67 ± 1.882ab</td>
<td>44.67 ± 4.880abc</td>
</tr>
<tr>
<td><strong>L. camara</strong></td>
<td>9.00 ± 2.251b</td>
<td>18.00 ± 2.677bc</td>
<td>0.00 ± 0.000b</td>
<td>5.00 ± 1.689bc</td>
<td>47.33 ± 5.163ab</td>
</tr>
<tr>
<td><strong>V. amygdalina</strong></td>
<td>8.33 ± 2.343bc</td>
<td>17.67 ± 2.608bc</td>
<td>0.00 ± 0.000b</td>
<td>7.00 ± 2.169ab</td>
<td>49.00 ± 5.281a</td>
</tr>
<tr>
<td><strong>T. diversifolia</strong></td>
<td>4.33 ± 1.352bc</td>
<td>11.67 ± 2.088cd</td>
<td>0.00 ± 0.000b</td>
<td>4.00 ± 1.328bc</td>
<td>35.67 ± 4.174bc</td>
</tr>
<tr>
<td><strong>T. vogelii</strong></td>
<td>3.67 ± 1.385bc</td>
<td>10.00 ± 2.255d</td>
<td>0.00 ± 0.000b</td>
<td>2.33 ± 0.962bc</td>
<td>33.33 ± 4.502c</td>
</tr>
<tr>
<td><strong>L. javanica</strong></td>
<td>8.67 ± 2.145b</td>
<td>16.00 ± 2.506bcd</td>
<td>0.00 ± 0.000b</td>
<td>7.00 ± 2.007ab</td>
<td>46.00 ± 5.127abc</td>
</tr>
<tr>
<td>Karate</td>
<td>2.67 ± 1.111c</td>
<td>0.33 ± 0.333e</td>
<td>11.67 ± 4.179a</td>
<td>1.00 ± 0.567c</td>
<td>4.00 ± 1.488d</td>
</tr>
<tr>
<td>Negative</td>
<td>20.00 ± 3.428a</td>
<td>31.67 ± 3.722a</td>
<td>0.00 ± 0.000b</td>
<td>11.67 ± 3.055a</td>
<td>56.67 ± 5.667a</td>
</tr>
</tbody>
</table>

#### One-way ANOVA

| F-statistic | 6.42*** | 12.30*** | 7.79 *** | 3.19** | 11.83*** |

**; *** significant at $P \leq 0.01$ and $P \leq 0.001$ respectively. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher’s Least Significant Difference (LSD) test
## Appendix 5: Plant damage

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Foliage beetles</th>
<th>Aphids</th>
<th>Spider mites</th>
<th>Mealybugs</th>
<th>Leafhoppers</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>B. pilosa</em></td>
<td>0.10 ± 0.019b</td>
<td>0.33 ± 0.044b</td>
<td>0.00 ± 0.000b</td>
<td>0.14 ± 0.068a</td>
<td>0.71 ± 0.050b</td>
</tr>
<tr>
<td><em>L. camara</em></td>
<td>0.10 ± 0.020b</td>
<td>0.26 ± 0.038bc</td>
<td>0.00 ± 0.000b</td>
<td>0.06 ± 0.015bc</td>
<td>0.78 ± 0.055b</td>
</tr>
<tr>
<td><em>V. amygdalina</em></td>
<td>0.09 ± 0.019b</td>
<td>0.30 ± 0.074bc</td>
<td>0.00 ± 0.000b</td>
<td>0.08 ± 0.019abc</td>
<td>0.80 ± 0.056b</td>
</tr>
<tr>
<td><em>T. diversifolia</em></td>
<td>0.04 ± 0.012dc</td>
<td>0.12 ± 0.020de</td>
<td>0.00 ± 0.000b</td>
<td>0.04 ± 0.011bc</td>
<td>0.48 ± 0.043c</td>
</tr>
<tr>
<td><em>T. vogelii</em></td>
<td>0.04 ± 0.011d</td>
<td>0.09 ± 0.017e</td>
<td>0.00 ± 0.000b</td>
<td>0.02 ± 0.009bc</td>
<td>0.49 ± 0.046c</td>
</tr>
<tr>
<td><em>L. javanica</em></td>
<td>0.10 ± 0.019b</td>
<td>0.21 ± 0.032cd</td>
<td>0.00 ± 0.000b</td>
<td>0.09 ± 0.019ab</td>
<td>0.73 ± 0.054b</td>
</tr>
<tr>
<td>Karate</td>
<td>0.02 ± 0.008d</td>
<td>0.00 ± 0.003e</td>
<td>0.51 ± 0.076a</td>
<td>0.01 ± 0.005c</td>
<td>0.04 ± 0.013d</td>
</tr>
<tr>
<td>Negative control</td>
<td>0.25 ± 0.032a</td>
<td>0.61 ± 0.059a</td>
<td>0.00 ± 0.000b</td>
<td>0.15 ± 0.025a</td>
<td>1.07 ± 0.064a</td>
</tr>
</tbody>
</table>

### One-way ANOVA

| F-statistic | 14.58*** | 19.87*** | 45.13*** | 3.26*** | 37.41*** |

*** significant at $P \leq 0.001$. Means within the same column followed by the same letter(s) are not significantly different at $(P = 0.05)$ using Fisher’s Least Significant Difference (LSD) test.
Appendix 6: Yield and yield components of bambara groundnuts

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of pods/plant</th>
<th>No. of seeds/pod</th>
<th>100 seeds weight (gm)</th>
<th>Pod yield (kg/ha)</th>
<th>Seeds yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. pilosa</td>
<td>14.50 ± 2.062ab</td>
<td>1.05 ± 0.020b</td>
<td>29.68 ± 4.496b</td>
<td>464.31 ± 107.848a</td>
<td>250.77 ± 65.888a</td>
</tr>
<tr>
<td>L. camara</td>
<td>16.25 ± 0.854a</td>
<td>1.10 ± 0.035ab</td>
<td>39.68 ± 3.713a</td>
<td>455.63 ± 54.497a</td>
<td>250.77 ± 36.938a</td>
</tr>
<tr>
<td>V. amygdalina</td>
<td>15.00 ± 1.225ab</td>
<td>1.07 ± 0.033b</td>
<td>38.50 ± 2.281ab</td>
<td>326.97 ± 13.254a</td>
<td>212.19 ± 19.290a</td>
</tr>
<tr>
<td>T. diversifolia</td>
<td>16.00 ± 1.291a</td>
<td>1.12 ± 0.022ab</td>
<td>39.90 ± 2.327a</td>
<td>493.25 ± 86.765a</td>
<td>289.35 ± 36.938a</td>
</tr>
<tr>
<td>T. vogelii</td>
<td>14.75 ± 1.315ab</td>
<td>1.06 ± 0.009b</td>
<td>36.85 ± 2.137ab</td>
<td>474.54 ± 62.199a</td>
<td>289.35 ± 36.938a</td>
</tr>
<tr>
<td>L. javanica</td>
<td>12.00 ± 1.581ab</td>
<td>1.17 ± 0.049a</td>
<td>28.85 ± 2.156b</td>
<td>472.03 ± 115.895a</td>
<td>250.77 ± 65.888a</td>
</tr>
<tr>
<td>Karate</td>
<td>13.25 ± 2.462ab</td>
<td>1.10 ± 0.019ab</td>
<td>32.83 ± 3.217ab</td>
<td>331.98 ± 116.695a</td>
<td>192.90 ± 66.823a</td>
</tr>
<tr>
<td>Negative</td>
<td>11.25 ± 1.377b</td>
<td>1.07 ± 0.013b</td>
<td>33.05 ± 5.312ab</td>
<td>383.49 ± 130.526a</td>
<td>231.48 ± 83.343a</td>
</tr>
</tbody>
</table>

One-way ANOVA

| F-statistic     | 1.29* | 1.92* | 1.69* | 0.52ns | 0.37ns |

*significant at $P \leq 0.05$ and ns means non-significant at $P \leq 0.05$. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) using Fisher’s Least Significant Difference (LSD) test.