EFFECTIVENESS OF INDIGENOUS TREE SPECIES (*Spirostachys africana*) EXTRACTS AGAINST *Sitophilus zeamais* (Mostschulsky)

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A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE

DEPARTMENT OF PLANT PRODUCTION

SCHOOL OF AGRICULTURE

UNIVERSITY OF VENDA

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JUNE 2015



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DECLARATION

I, Zwivhuya Leonard Ndou, declare that this thesis submitted by me to the Department of Plant Production, School of Agriculture, at the University of Venda, has never been submitted to this university or to any other university. This is my own work and all sources used in the development of the thesis are properly acknowledged.

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ACKNOWLEDGEMENTS

I wish to convey my heartfelt gratitude to my supervisor, Prof E.C. Kunjeku, for her patience, constructive criticism, advice, support, guidance and encouragement throughout my research.

I am also grateful for the assistance I got from my co-supervisor, Mr P.E.L Mojapelo for his valuable advice, patience and for sharing his knowledge in the use of HPLC, GC and GC-MS.

I would like to acknowledge Mr K.C. Chigayo and Mr T.R. Mudau for their timely and highly valued technical assistance in the chemical analysis of the plant crude extracts.

I would like to convey my very special thanks to Chief Netshidzivhe of Tshidzivhe Village in Ha-Tshivhasa and to the late Chief of Mauluma (VhaMusanda, Khosi Vho-Ifa Nndwaya Miomva Ravele) and Chief Mavhunga (VhaMusanda, Khosi Vho-Lugisani Adam Mavhunga) in Nzhelele, for their support and advice on the use of indigenous plants as vegetables and grain protectants.

I would also like to thank Mr M.E. Gereda, Mr M. Radzilani and Mr R. Tshidzumba for assisting me with collection of the plant materials in the mountain and for the collection of the infested maize grain. Also, my thanks go to all people who helped me to carry out my research project, not forgetting my family and friends for being there for me during hard and stressful times.

I gratefully and humbly acknowledge the financial support I received from the Maize Trust to carry out my study.

Finally, I wish to thank Almighty God for granting me strength to do my studies.

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TABLE OF CONTENTS

DECLARATION i
ACKNOWLEDGEMENTS ii
TABLE OF CONTENTS iii
LIST OF TABLES vi
LIST OF FIGURES vii
LIST OF PLATES ix
LIST OF APPENDICES x
LIST OF ABBREVIATIONS xi
ABSTRACT xii

CHAPTER 1: INTRODUCTION 1

1.1 Background 1
1.2 Problem Statement 2
1.3 Justification 3
1.4 Study aim and objectives 3
1.5 Hypothesis 3
1.6 Null hypothesis 3

CHAPTER 2: LITERATURE REVIEW 4

2.1 Maize uses and storage 4
2.2 Insect pests affecting stored maize 5
2.3 *Sitophilus zeamais* 6
2.3.1 Effect of *Sitophilus zeamais* on stored maize 6
2.3.2 Biology and ecology 6
2.4 Management of infestations in storage 7
2.4.1 Chemical control 7
2.4.2 Biological control 8
2.4.3 Environmental manipulation 8
2.4.4 Botanical Extracts 9
2.5 The tamboti (*Spirostachys africana*) tree 11
2.6 Plant extraction using chromatography techniques 12
2.7 Natural organic fluorine compounds as insecticides 13

CHAPTER 3: MATERIALS AND METHODS 15

3.1 Experimental site 15
3.2 Sources of material: Insects, maize and plant extracts 15

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3.2.1 Collection of plant materials and preparation of extracts 15
3.2.2 Maize collection 17
3.2.3 Culturing of insects 17
3.3 Effect of plant powder on *S. zeamais* 18
3.4 Extraction of crude extracts from plant materials 19
3.4.1 Contact toxicity by topical application 19
3.4.2 Determining repellent effects of crude extracts. 20
3.4.3 Feeding deterrence. 22
3.5 Separation and isolation of active ingredients of *S. africana* by High Performance Liquid Chromatography (HPLC) 24
3.6 Purity of compounds in collected fractions 25
3.7 Identification of compounds in collected crude extracts using GC-MS 25
3.8 Data analysis 25

CHAPTER 4: RESULTS OF BIOLOGICAL STUDIES 26

4.1 Introduction 26
4.2 Toxicity of *S. africana* powders against *S. zeamais* at 30, 60 and 90 days post treatment. 26
4.2.1 Effect of *S. africana* powders against *S. zeamais* infestation on maize grain at 30 days post treatment 26
4.2.2 Effect of *S. africana* powders on mortality of *S. zeamais* at 60 days post-treatment. 28
4.2.3 Effect of *S. africana* powders on mortality of *S. zeamais* at 90 days post-treatment. 30
4.2.4 Percent Weight loss of maize grain caused by *S. zeamais* at 30 days post treatment 31
4.2.5 Percentage weight loss of maize grain caused by *S. zeamais* at 60 days post-treatment 33
4.2.6 Percentage weight loss of maize grain caused by *S. zeamais* at 90 days post treatment. 35
4.2.7 Effect of *S. africana* on adult emergence of *S. zeamais* at 60 days post treatment. 37
4.2.8 Effect of *S. africana* on adult emergence of *S. zeamais* at 90 days post treatment. 38
4.3 Laboratory bioassay studies of *S. africana* crude extracts 40
4.3.1 Contact toxicity of *S. africana* crude extracts on adult *S. zeamais* 40

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4.3.2 Repellent response effects caused by *S. africana* crude extracts against *S. zeamais* 42
4.3.3 Feeding deterrence of *S. africana* crude extracts against *S. zeamais*. 44

CHAPTER 5: RESULTS OF CHROMATOGRAPHY STUDIES 47

5.1 Analysis of crude extracts by HPLC and GC for the collected pure compounds 47
5.1.1 Collection of separated compounds from crude extracts of *S. africana* root 47
5.1.2 Collection of separated compounds from crude extracts of *S. africana* outer bark 48
5.1.3 Chromatogram documentation of identified compounds of *S. africana* root crude extracts 49
5.1.4 Chromatogram documentation of identified compounds of *S. africana* outer bark crude extracts 50
5.2 Identification of the constituents in *S. africana* crude extracts 51
5.2.1 Possible chemical composition of *S. africana* root crude extracts 51
5.2.2 Possible chemical crude extracts of *S. africana* outer bark crude extracts 52

6. DISCUSSION 54
7. CONCLUDING REMARKS AND RECOMMENDATIONS 58
REFERENCES 59
APPENDICES 69

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LIST OF TABLES

Table 1. HPLC Analysis.....24

Table 2. Mortality due to root crude extracts applied topically (contact toxicity) to *S. zeamais*.....40

Table 3. Mortality due to outer bark crude extracts applied topically (contact toxicity) to *S. zeamais*.....41

Table 4. Mean percent repellency for the root crude extracts of *S. africana* against *S. zeamais*.....42

Table 5. Mean percent repellency for outer bark crude extracts of *S. africana* against S. zeamais.....43

Table 6. Possible chemical compounds in root crude extracts.....51

Table 7. Possible chemical compounds in outer bark crude extracts.....52

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LIST OF FIGURES

Figure 1. Mortality of *S. zeamais* adults exposed to varying doses of *S. africana* powders at 30 days post treatment.....27

Figure 2. Mortality of *S. zeamais* adults exposed to varying doses of *S. africana* powders at 60 days post treatment.....29

Figure 3. Mortality of *S. zeamais* adults exposed to varying doses of *S. africana* powders at 90 days post treatment.....30

Figure 4. Maize grain weight loss caused by *S zeamais* treated with *S. africana* powders in varying doses at 30 days post treatment.....32

Figure 5. Maize grain weight loss caused by *S. zeamais* treated with *S. africana* powders in varying doses at 60 day post treatment.....33

Figure 6. Maize grain weight loss caused by *S. zeamais* treated with *S. africana* powders in varying doses at 90 day post treatment.....35

Figure 7. Effect of *S. africana* powders on adult emergence of *S. zeamais* at 60 day post treatment.....37

Figure 8. Effect of *S. africana* powders on adult emergence of *S. zeamais* at 90 days post treatment.....39

Figure 9. Mean mortality of adult *S. zeamais caused* by *S. africana* crude extracts.....41

Figure 10. Mean percent repellency response of *S. zeamais* caused by *S. africana* crude extracts.....43

Figure 11. Undamaged maize grain by adult *S. zeamais* treated with *S. africana* crude extracts at varying doses.....44

Figure 12. Maize grain weight loss caused by adult *S. zeamais* treated with *S. africana* crude extracts at varying doses.....46

Figure 13. Chromatograms of roots compounds not well separated at the beginning.....47

Figure 14. Chromatogram of root compound showing poor separation at the beginning and good separation detected at the end with two different compounds named peak 1 and peak 2 with improved separation.....48

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Figure 15. Chromatograms of outer bark compounds not well separated at the end.....48

Figure 16. Chromatogram of outer bark compounds showing poor separation at the beginning and good separation detected at the end with two different compounds named peak 1 and peak 2 with improved separation.....49

Figure 17. Root crude extracts gas chromatogram.....49

Figure 18. Gas Chromatogram of root extracts.....50

Figure 19. Outer bark crude extracts gas chromatogram.....50

Figure 20. Outer bark extracts Gas Chromatograms.....51

Figure 21. GC-MS spectra for *S. africana* root crude extracts and corresponding molecular structures.....52

Figure 22. GC-MS spectra for *S. africana* outer bark crude extracts and corresponding molecular structures.....53

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LIST OF PLATES

Plate 1. Plant materials collected from S*pirostachys africana*.....16

Plate 2. Powdered material from *Spirostachys africana*.....16

Plate 3. Maize infested with *Sitophilus zeamais*.....17

Plate 4. Sieving infested maize grain treated with plant powder.....18

Plate 5. Experimental layout of petri dishes for contact toxicity bioassay.....20

Plate 6. Experimental layout of perforated containers with nylon mesh for repellency bioassays.....21

Plate 7. Maize weevil repelled by extracts crawling to the nylon mesh.....21

Plate 8. Measuring of crude extracts before treating maize grains.....22

Plate 9. Transfering maize weevils to maize grain treated with crude extracts.....23

Plate 10. Layout of feeding deterrent experiment.....23

Plate 11. Damage and undamaged maize grain.....45

Plate 12. Maize grain bored by *S.* zeamais.....45

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LIST OF APPENDICES

Appendix I: Results for toxicity effect of plant powders against *S. zeamais* at 30 days post treatment.....69

Appendix II: Results of mortality caused by *S. africana* powders at 60 and 90 days post treatment.....74

Appendix III: Results for maize grain weight loss caused *S. zeamais* at 30 days post treatment.....84

Appendix IV: Results for maize grain weight loss caused by *S. zeamais* at 60 and 90 days post treatment.....89

Appendix V: Results for adult emergence of *S. zeamais* treated with plant powders against *S. zeamais* at 60 and 90 days post treatment.....99

Appendix VI: Laboratory bioassays of *S. africana* crude extracts against *S. zeamais*.....109

Appendix VII: Raw data of effect of *S. africana* powder against *S. zeamais* at 30, 60 and 90 days post treatment.....116

Appendix VIII: Raw data of laboratory bioassay of *S. africana* root and outer bark crude extracts against *S. zeamais*.....129

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
Amu	atomic mass unit
CRD	Completely Randomized Design
FAO	Food and Agriculture Organization
GC	Gas chromatography
GC-MS	Gas chromatography–mass spectrometry
HPLC	High performance liquid chromatography
MIC	Minimum inhibitory concentration
MBC	Minimum bacterial concentration
ml	millilitres
min	minutes
mg	milligram
µg	microgram
µl	microlitres
µm	micrometres
NDA	National Department of Agriculture
Pts/s	points per second/ sampling rate
nm	nanometres
UV	ultraviolet
H	hour
g	gram
°C	degree Celsius
°/min	degree per minute

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ABSTRACT

Maize (*Zea mays* L.) is an important food in southern Africa, and it constitutes a major dietary proportion for many households. The maize weevil, *Sitophilus zeamais*, reduces both quality and quantity of stored grain through boring the grains and eating the inner part of the maize seed. In Africa, small scale farmers use insecticidal plant extracts as a cheaper and a safer alternative to synthetic insecticides. *Spirostachys africana* extracts are traditionally used in Vhembe District as insect repellents for protecting grains against storage pests. This research study was carried out to assess the insecticidal activity of *S. africana* extracts from different parts of the plant. Toxicity of bark, leaves, fruits and roots of the *S. africana* powders at three storage intervals (30d, 60d and 90d) were evaluated and data were collected on mortality, weight loss and progeny adult emergence of *S. zeamais*. The result showed that *S. africana* powders have toxicity effects on *S. zeamais* but differed with dosages applied and exposure period. The findings showed that, after a prolonged exposure period, there was suppression of adult emergence and mortality of weevils, and increase in maize weight loss. Powders from the root and outer bark were the most effective at a dosage rate of 2.5 g and 5 g/ 50 g maize respectively. All powders have insecticidal effects against *S. zeamais*, but are only suitable for short term storage. Chemical analysis of the *S. africana* crude extracts revealed one major possible compound for each crude extract. Root crude extracts components representing 95.4% of the identified compound was trifluoracetic acid and outer bark crude extracts (35.4%) was 1,2-benzenedicarboxylic acid. Bioassay results obtained showed that outer bark and root crude extracts caused 44 to 56% mortality after 2 days of application. Repellency tests showed a maximum of 90% repellency one hour after treatment. Feeding deterrence test showed undamaged grain seed of around 75% and weight losses (8%) when treated with crude extracts. This study demonstrated the potential of *S. africana* root and outer bark extracts as grain protectants against *S. zeamais*.

Keywords: Bioassays, crude extract, feeding deterrence, mortality, repellency, *Sitophilus zeamais*, *Spirostachys africana*.

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CHAPTER 1: INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) is an important food crop in Africa, and it constitutes a major dietary proportion for many households (Mboya *et al.,* 2011). Maize is a staple food that provides more carbohydrates, protein, iron, vitamin B and minerals than wheat and sorghum (IITA, 2009).

In Africa, maize production is affected by storage insect pests, resulting in economic loss (Udo, 2005). Insects that infest maize grains are divided into two groups, namely primary and secondary insect pests. Primary insect pests are those capable of penetrating and infesting the intact kernel of grain, and have immature stages developing within the kernel of grain (Golob, 2009). The major primary pests are the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae), rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), and the lesser grain borer, *Rhyzopertha dominica* (F.), (Coleoptera: Bostrichidae).

Secondary insect pests cannot infest the whole grain, but they feed on grain damaged by primary pests and on broken kernels and debris. The immature stages of secondary insect pests are found externally on the grains and cannot initiate infestation (Golob, 2009). Major secondary maize grain pests include rust-red flour beetle, *Tribolium castaneum* (Herbst), (Coleoptera: Tenebrionidae), tropical warehouse moth, *Cadra cautella* (Walker) (Lepidoptera: Pyralidae), and Angoumois grain moth, *Sitotroga cerealella* (Olivier), (Lepidoptera: Gelechiidae).

The infestation of maize grain leads to yield losses ranging from 30 to 50 % after six months of storage (Taylor, 1971). *Sitophilus zeamais* has been recognised for many years as an increasingly important insect pest of maize and other grain cereals in storage (Abebe *et al.,* 2009).

In Africa, the use of synthetic insecticides to control storage grain insect pests is not affordable to many farmers. Resource-poor farmers rely on insecticidal plant products (Gold, Bagabe and Sendenge, 1999; Carvalho, 2006). Even though synthetic insecticides have contributed to an increase in agricultural productivity, their widespread usage is of global concern because of the ability by insects to develop resistance. They also leave toxic residues on food, are environmental hazards and have undesirable effects on non-target insects (Isman, 2008). Therefore, alternative control strategies which are environmentally friendly, less persistent, and selective towards target pests are desirable (Isman, 2006).

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Copping and Menn (2000) have stressed that some farmers use insecticidal plant extracts as a cheaper and safer alternative to synthetic insecticides. Plant extracts can form part of the integrated pest management (IPM) for insect control.

In Africa, botanical insecticides have long played a vital role in the protection of stored agricultural products. However, their practices were abandoned during the era of synthetic insecticides (Isman, 2006). Problems such as environmental contamination, genetic resistance in insect pests, and toxic residues in food and feed, brought them back to the fore. Botanical insecticides are safe, biodegradable, have low mammalian toxicity, and pose little or no danger to the environment if used in small amounts (Belmain *et al.*, 2001). Jacobson (1982) stressed the importance of some botanical insecticides having a wide range of biological activity on insect pests. They can act as growth inhibitors, oviposition deterrence, feeding repellents or as toxicants. Botanical insecticides currently used for insect control are pyrethrum, rotenone, neem, essential oils, ryania, nicotine, and sabadilla (Isman, 2006).

Most plant-derived insecticides are commonly used in the form of solvent extracts, slurries, powders, volatiles and oils or as shredded segments of plant parts (Keita *et al.*, 2001). A large number of plant extracts from various herbs are used as fumigants against insects, and they can induce 90% mortality in adult populations of the grain weevil within 24 hours of application (Shaaya *et al.*, 1997). The insecticidal activities of most plant extracts known to be effective in controlling the larvae of most insect species include extracts from china berry (*Melia azedarach*), custard-apple (*Annona reticulate)* and neem (*Azadirachta indica*). China berry, custard-apple and neem extracts have shown toxicity in the adult and larval maize weevil (*S. zeamais)* after 24 hours of topical application (Isman, 2006; Morgan, 2009).

In some plants, the presence of certain chemicals prevents insects from feeding on them, resulting in starvation and eventual death (Morgan, 2009). For example, *Annona reticulate* and *Azadirachta indica* proved to be effective insect repellents when they exhibited strong repellency toward *T. casteneum* and *S. oryzae,* both of which are serious pests of stored grain (Morgan, 2009).

1.2 Problem Statement

Dried chips of *Spirostachys africana* are used traditionally as an insect repellent against storage pests (Mvumi, Giga and Chiuswa, 1995). *Spirostachys africana* is known to provide short term protection against *S. zeamais* (Chikukura, Mvumi and Chenzara, 2011). Currently, the whole bark of *Spirostachys africana* is used by subsistence farmers in Vhembe District, Limpopo Province, in the Republic of South Africa, to protect and extend

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maize grain storage by mixing dried bark with grain (Musanda Tshidzivhe., pers. comm.). However, further research needs to be conducted to assess the efficacy and residual properties of plant powder extracts, and to determine the optimum rate of application so as to avoid unnecessary application (Chikukura *et al.,* 2011). The efficacy of the insecticidal activity of different plant parts of *S. africana* is unknown, neither is the chemical composition of the plant extracts.

1.3 Justification

The study will contribute to the understanding of the effectiveness of *Spirostachys africana* in controlling *S. zeamais*. The study will help in the identification of some of the active compounds with insecticidal activity against *S. zeamais.*

1.4 Study aim and objectives

The aim of the study was to assess the insecticidal activity of various plant parts (leaves, fruits, outer bark, inner bark and roots) of *Spirostachys africana* extracts on *S. zeamais*.

Specific objectives were:

(i) To evaluate the effect of powders from bark, leaves, fruits and roots of *S. africana* on the biology of *S. zeamais*;

(ii) To determine the mortality of *S. zeamais* due to different extracts from *S. africana;*

(iii) To determine the repellent and feeding deterrent effects of *S. africana* on *S. zeamais*; and

(iv) To identify insecticidal compounds from plant extracts by chromatography.

1.5 Hypothesis

Extracts from different parts of *S. africana* affect the development and cause mortality of *S. zeamais* in the same way.

1.6 Null hypothesis

Extracts from different parts of *S. africana* do not affect the development and cause mortality of *S. zeamais* in similar ways.

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CHAPTER 2: LITERATURE REVIEW

2.1 Maize uses and storage

Maize, *Zea mays* L., belongs to the family Gramineae or Poaceae. Maize is the world's third most important staple crop after rice and wheat (IITA, 2009). Nutritionally, maize contains starch, water, protein oil, sugar and fibre (IITA, 2009). In South Africa, about 60% of maize produced is white, and it is primarily used for human consumption as a staple food, while 40% of yellow maize produced is mostly used for animal feed (NDA, 2011). Maize is the second largest crop produced in South Africa after sugar cane. Maize is processed into products such as maize meal, maize grits, cornflakes and snacks (IITA, 2009). Maize also serves as a raw material for other manufactured products such as paper, paint, textiles, and medicines (NDA, 2011). It is estimated that South Africa produces 11.7 million tonnes of maize per annum (FAO, 2012).

In South Africa, inadequate post-harvest storage contributes significantly to food insecurity (Ntlokwana 1999, cited by Thamaga-Chitja *et al.*, 2004). In South Africa, most small-scale farmers store maize in traditional grain stores made of grass, wood and mud (Thamaga-Chitja *et al.*, 2004). This does not guarantee protection against major storage insect pests. Commercial farmers store maize in metallic silos for both short and long term storage (Thamaga-Chitja *et al.*, 2004).

Some traditional methods of storage are more effective than others, and this depends on the nature of grain being stored and its resistance to storage pests (Modi, 2004). For short term storage, maize grain is stored in calabashes, clay pots, jute polypropylene bags and wooden baskets (Thamaga-Chitja *et al.*, 2004). The use of these structures allows air to flow freely through the grain, and this enhances the drying process, but also makes the grain vulnerable to attack by insect pests (Thamaga-Chitja *et al.*, 2004). For long term storage, air tight plastic containers are used to maintain the viability and vigour of grain, while reducing infestation by insects (Thamaga-Chitja *et al.*, 2004).

Wooden structures placed above the cooking fireplace are traditionally used in South Africa to store maize so that the smoke from the hearth keeps the seeds dry and reduces insect and disease damage (Modi, 2004). It is also reported that the combined effect of smoke and high temperatures generated by smoke has a detrimental effect on seed quality, which leads to low germination (Modi, 2004; Thamaga-Chitja *et al.*, 2004). Rural farmers in Limpopo Province (Vhembe District) use traditional granaries made out of mud or clay to store maize. These granaries provide a cool environment that keeps grains viable for germination, and they can store grain for periods of up to 12 months if properly built, especially when grain is

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treated with plant bark from *Spirostachys africana* and *Combretum molle*. Grains stored in such traditional granaries, without these plants, are vulnerable to insect pest damage (Musanda Tshidzivhe, pers. comm.).

In Vhembe, indigenous ways of extended maize storage included burying maize grain mixed with *S. africana* bark in underground pits of 2-2.5 m in depth. This practice has been abandoned by local farmers as a long term storage for 2 to 3 years. The pits were used for large scale storage of grains. The underground pit was prepared by selecting and digging an appropriate area within the cattle kraal. Fire was made inside the pit to dry up the walls to reduce moisture inside the pit. The ash from the fire was known to prevent insect infestation. When filling the pit, maize grain and *S. africana* bark were mixed together. This was known to effectively eliminate insect pests and pathogens (Musanda Tshidzivhe, pers. comm.).

2.2 Insect pests affecting stored maize

Insects are considered to be a principal cause of maize grain loss (Harney, 1993). More than 37 species of arthropod pests are associated with maize grain in storage (Abraham 1997, cited by Sori and Ayana, 2012). In South Africa, two major orders of insects namely Coleoptera and Lepidoptera are associated with post-harvest grain (Harney, 1993). Infestation by post-harvest pests commences in the field, but most damage occurs during the storage (Demissie *et al.*, 2008).

Insect pests affect both quality and quantity of stored grain by destroying 20 to 30% of stored grain in tropical regions and 5 to 10% in temperate regions (Demissie *et al.*, 2008). One of the major insect pests affecting maize grain in storage in Southern Africa is *S. zeamais* (Dhliwayo and Pixley, 2004). As primary pests, maize weevils are of importance as they enter intact grain providing access for secondary stored product insects such as *Tribolium castaneum* and *Sitotroga cerealella* (Abebe *et al.*, 2009).

Among insect pests affecting maize in storage, *Tribolium castaneum* (Herbst) is considered a secondary pest when it coexists with primary pests such as *Sitophilus zeamais* (Motschulsky), *Callosobruchus maculates* (Fabricius), *Prostephanus truncatus* (Horn), *Rhyzopertha dominica* (Fabricius) and the secondary pest *Sitotroga cerealella* (Olivier) (Allotey and Morris 1993, cited by Sousa *et al.*, 2009).

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2.3 *Sitophilus zeamais*

2.3.1 Effect of *Sitophilus zeamais* on stored maize

S. zeamais infestation is a major post-harvest problem affecting stored grains in tropical and subtropical regions (Abebe *et al.*, 2009). More than 96 million tonnes of maize grain are lost annually all over the world through infestation by *Sitophilus* species (FAO, 1985). *S. zeamais* causes damage to the grain by boring into the grains and eating the inner part, and this reduces maize weight and quality (Adda *et al.*, 2002). The infestation causes a significant loss of 38% in weight and nutritional value, and results in low percent germination, and loss of market value (Adda *et al.*, 2002).

2.3.2 Biology and ecology

S. zeamais (Motschulsky) is in the Curculionidae Family, which includes *S. granarius* (granary weevil) and *Sitophilus oryzae* (rice weevil) (Harney 1993, cited by Fakude, 2008). The adults are active fliers and they are about 3 to 4.8 mm in length. They have a reddish to brown to black colour. The rostrum of the male *Sitophilus* is rough, distinctly shorter and wider than that of the female, while the rostrum of the female is smooth, shiny, distinctly longer and narrower than that of the male.

The weevil undergoes complete metamorphosis with four development stages; namely egg, larva, pupa and adult. Adult females chew grains, creating small holes in which about 350 eggs are laid in clusters on the grains (Smit, 1964, cited by Fakude, 2008). Eggs are laid at temperatures between 15 and 35 °C with an optimum at about 25 °C, and grain moisture content of over 10% but not above 32% (Smit, 1964, cited by Fakude, 2008). There are 3 to 4 larval instars, which take an average of 18 days to develop. The pupal stage takes an average of 6 days, and upon transformation, the adult insect will remain within the kernel for 3 to 4 days until it matures. Mating does not occur before the adults are 3 days old.

Optimum temperatures of about 25 to 30 °C and relative humidity of 65 to 75% are suitable for growth of maize weevil populations on stored maize (Harney 1993, cited by Fakude, 2008). The life cycle of this species takes around 30 days from eggs to adult (Harney 1993, cited by Fakude, 2008). Adults can live for up to 5-6 months depending on the humidity and temperature of grains (Harney 1993, cited by Fakude, 2008).

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2.4 Management of infestations in storage

2.4.1 Chemical control

Chemical control is used in the management of infestation of stored maize in the form of contact insecticides and fumigants (Rajendran and Muralidharan, 2001). Contact grain insecticides widely used as grain protectants in storage are malathion, fenitrothion, dichlorvos, pirimiphos-methyl and chlorpyrifos-methyl (Snelson 1987, cited by Frank, 1996). However, their constant use has globally led to insect resistance development (Fields and White, 2002). Even though those insecticides have a relatively low mammalian toxicity (Watters *et al.*, 1983), and are degradable, they are considered not safe, based on their toxicological re-evaluation (Fields and White, 2002).

Methyl bromide and phosphine gas have been widely used for disinfection of commodities and storage treatment (Leesch, 1995). Phosphine gas is widely used throughout the world to control stored insects without moving the grain out of storage. This is due to its effectiveness as a fumigant as it can move readily through grain from the point of application (Rajendran and Muralidharan, 2001). Phosphine requires 4 to 5 days to disinfect grain (Taylor, 1971). Conventional use has resulted in failure to control insects, as insects have developed resistance to it (Collins *et al.*, 2002). *Sitophilus oryzae, Tribolium castaneum* and *Rhizopertha dominica* have been reported to be resistant to phosphine as well (Collins *et al.*, 2002).

Fumigants such as hydrogen cyanide are considered to be more effective in suppressing insects (Fields and White, 2002). Use of this fumigant is discouraged because it has high dermal toxicity (Fields and White, 2002). Hydrogen cyanide is used for disinfestations of rodents in places such as mills and ships, but mostly, it is widely used for the control of insects in cereal grain and other dry products such as dried fruits and tobacco (Hooper *et al.*, 2003).

Commonly used maize grain storage insecticides in South Africa include carbaryl, carbosulfan, bromoxynil phenol and oxydemeton-methyl (commercial storage); malathion, deltamethrin, fenitrothion and chlorpyriphos-methyl (small scale storage) and pirimiphos-methyl by subsistence storage farmers (Quinn *et al.*, 2011).

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2.4.2 Biological control

Biological control is widely practiced in the management of storage grain insect pest infestation (Mahr *et al.*, 2001). The suitability of parasitoids for the control of pest organisms depends on compatibility of the parasitoids with the storage environment because parasitoids suitable for bio-control should be able to find hosts over large distances and in considerable grain depths in the storage facility (Cortesero1997, cited by Adarkwah *et al.*, 2008).

Rural poor small-scale subsistence farmers and their families cannot afford modern post-harvest techniques of biological pest control (Markham *et al.*, 1994). In Africa, biological control of releasing natural enemies of stored grain insect pest infestations have been reported as a promising approach for controlling storage insects in countries such as Tanzania and Togo (Markham *et al.*, 1994). Wen and Brower (1994) reported that the single and multiple releases of the parasitoids can be used to suppress up to 90% of *S. zeamais* population.

Parasitoids of *Sitophilus* species occur in nature and include parasitoids of Order Hymenoptera (Pteromalidae, Bethylidae) such as *Anisopteromalus calandrae* (Howard), *Choetospila elegans* (Westwood), *Lariophagus distinguendus* (Förster), *Theocolax elegans* (Westwood), and *Cephalonomia tarsalis* (Ashmead) (Lord, 2006; Flinn *et al.*, 2006). For example, *Lariophagus distinguendus* (Förster) is a wasp parasite on the larvae and pupae of several beetle species infesting stored grain products. These wasps lay their eggs on host weevil larvae, and the parasitoid larvae will develop in the weevil larvae, ultimately killing the host weevil when they emerge as mature larvae before pupation (Adarkwah *et al.*, 2008; Schöller, 2010). Recently, *L. distinguendus* has been used for biological control of the *Sitophilus zeamais* because of its ability to locate hosts at considerable depths within the grain (Adarkwah *et al.*, 2008; Schöller, 2010).

2.4.3 Environmental manipulation

Exposing stored grain insects to the concentration of atmospheric gases such as oxygen, nitrogen and carbon dioxide to produce gas mixtures which are toxic to insects is widely practised as a bio-rational substitute for chemical fumigations (Navarro, 2006). Introducing carbon dioxide from a gas cylinder into a gas-tight silo has proved to be a viable alternative to phosphine in managing infestation of grain (Jay, 1986). Carbon dioxide gives effective control when maintained for a period longer than 14 days at a concentration exposure of around 40% carbon dioxide (Kashi, 1981). According to observations made by Li *et al.*

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(2009), stored product insects such as rusty grain beetle, *Cryptolestes furrugineus* (Stephens) were killed by a high concentration of nitrogen gas.

Insect infestation can be controlled by manipulating temperatures, and this can result in the reduction of the rate of development, feeding reproduction and survival (Banks and Fields, 1995). Stored grain insects have a broad range of tolerances to hot and cold temperatures (Maier *et al.*, 1996). At lower temperatures, insect metabolism slows down and development ceases at temperatures below 10 °C. Prolonged storage at temperatures of 10 °C and below proved to be lethal to eggs of the stored product moths of the genera *Ephestia* and *Plodia* (Maier *et al.,* 1996).

Insects can be controlled by using the method of high temperature/short time (HTST) because grains exposed to hot air with an inlet temperature of 30 °C to 35 °C for a 40 second exposure time proved to be lethal, causing 99% mortality on *S. granarius* and *Prostephanus trancatus* (Mourier and Poulsen, 2000). This finding was also supported by Fields and White (2000) who showed that high temperatures of 35 °C can prevent the development of *Sitophilus* species and *T. castaneum* larvae and pupae into adults (Fields and White, 2002). High temperatures have adverse effects on insects because they destroy the insect's nervous system, disrupt plasma membranes, inactivate major glycolysis enzymes, denature protein, nucleic acids, carbohydrates and lipids (Neven, 2000).

Aeration cooling greatly reduces insect and mould activity in stored grain, as well as preserve grain quality (Navarro, 2006). Aeration of grain bulk with ambient air is a widely used method after harvesting to cool the grain. This method has been reported to effectively prevent pest build-up in storage (Navarro, 2006).

2.4.4 Botanical Extracts

Botanical extracts are used as insect repellents, toxicants, larval growth inhibitors, feeding deterrents and chemosterilants (Jacobson, 1982). Bekele and Hassanali (2001) reported that botanical extracts contain secondary compounds that are responsible for toxic action with combined effects. For example, the blend effects of essential oil constituents extracted from *Ocimum kilimandsharicum* (Gürke) and *Ocimum kenyense* were found to be effective toxicants on maize weevils and lesser grain borers. However, Abdullahi and Muhammad (2004) reported 40.9% adult emergence of *C. maculatus* on cowpea treated with *Piper guineense*, while a study conducted by Asawalam *et al.* (2007) revealed only 10% and 5% adult emergence of *S. zeamais* on maize treated with the same plant powder. *Capsicum frutescens* and *Nicotiana tabacum* were also found to affect adult emergence of *S. zeamais* on maize grains, showing 10% and 12% emergence, respectively (Asawalam *et al.*, 2007).

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Oparaeke and Dike (1996) reported that the products of *Allium sativum* and *Cymbopogon citratus* controlled *C. maculatus* on stored cowpea. The plant powders gave 100% mortality after 7 days of treatment. Asawalam *et al.* (2007) recorded mortality higher than 79% on *S. zeamais* treated with *Piper guineense* on maize grains. These findings were confirmed by Danjumma *et al.* (2009), who showed that 96.67% *S. zeamais* adults were effectively killed by treatment with *A. sativum* at a rate of 2.0 g/ 50 g maize grains.

Dawit and Bekelle (2010) reported that *Citrus sinensis* peel powder was found to be effective in repelling *Zonantes subfasciatus* on haricot bean seed. Powdered *Azadirachta indica* was observed to give high repellency after 24 hours of exposure at a dosage of 7 g per 50 g of maize, whereas *C. citratus* has an average repellency at a dosage of 5.80 g against *S. zeamais* (Parugrug and Roxas, 2008).

The ovicidal effects of plant extracts like *Jatropha curcas* leaves were observed to reduce oviposition of *C. maculatus* by 30%, at a plant powder concentration of 2 g/ 20 g cowpea (Umar, 2008). The same observation was made by Oparaeke *et al.* (2005), who argued that oviposition of *C. maculatus* was controlled by *Allium cepa* at the dosage rate of 6 g/100 g seeds.

Plant essential oils and their components are used to disinfect stored commodities. Unlike conventional fumigants, they are locally available, have low mammalian toxicity and are biodegradable (Isman, 2000). Essential oil extracts of *Blumea balsamifera* leaves have five active compounds which have strong fumigant toxicity against *S. zeamais* adults (Chu *et al.*, 2012). *B. balsamifera* extracts are used as toxicant fumigants. Exposing *S. zeamais* to the extracts caused toxicity through inhalation (Chu *et al.*, 2012).

Insecticidal activity of *Azadirachta indica* crude extracts is due to triterpenoids which have feeding deterrents and stomach toxicity effects on the insect's digestive system (Isman, 2006). *A. indica* crude extracts inhibit feeding, leading to death and abnormality of the following generation (Vergara *et al.*, 1997; Carpinella *et al.*, 2003). Insecticidal activity of azadiractine (a tetranotriterpenoid) was also found on the leaf and fruit extracts of *Azadirachta indica* as growth inhibitors regulating insects (Isman, 2006). Neem plant extracts are also known to cause 72 to 90% repellency due to the presence of the azadirachtine active component. Azadirachtine can be found in the bark, leaves, fruits and seeds of the neem trees (Morgan, 2009).

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2.5 The tamboti (*Spirostachys africana*) tree

Indigenous tree species such as the tamboti are traditionally used as grain insect protectants (Mvumi *et al.*, 1995; Chikukura *et al.*, 2011). The tamboti belongs to the family Euphorbiaceae, a large family comprised of 4 000 to 7 000 species in roughly 280 genera (Coates Palgrave, 1983). In South Africa, 39 genera of this family have been found (Van Wyk, 1974). It can grow up to between 10 and 18 m in height and is a medium-sized, semi-deciduous tree with a round crown, which occurs in low altitude bushveld, often in woodland (Van Wyk, 1974). The wood itself is almost indestructible and the carbon-dating samples collected from Zimbabwe Ruins (Great Zimbabwe) were reported to be 1240 and 1530 years old (Coates Palgrave, 1983).

The tamboti tree is found near dense stands in warm dry areas along rivers and drainage lines with poor drained soils. The tree is widely distributed in the lowveld and woodland regions of South Africa such as KwaZulu-Natal were they naturally occur stretching to Tanzania in the north (Coates Palgrave, 1983).

The tree is commonly known for its toxic milky latex that exudes from all parts of it (Coates Palgrave, 1983). The copious milky latex is very poisonous and causes extreme irritation to sensitive skin and severe pains and even damage to eyes (Coates Palgrave, 1983). However, the plant is valued for its numerous uses. For example, the leaves, bark and roots are traditionally used as medicinal decoction to cleanse the blood, to treat headaches and infested wounds, snake bites and cuts (Van Wyk, 1974).

Recently, *S. africana* has been used as a traditional medicinal plant with unknown anti-HIV active compounds (Chinsembu and Hedimbi, 2010). The plant is normally used by farmers as dried wood chips mixed with grain to provide protection against grain insects (Mvumi *et al.*, 1995).

Subsistence farmers in Vhembe District, Limpopo Province, in the Republic of South Africa, use *S. africana* extracts to protect grain against insect pest infestation. Dried and fresh parts of the plant are mixed with grain before and after storage. Fresh outer bark plant materials in the form of small chips are mixed or added fresh to sacks of grain to discourage insects from feeding, whereas in the granary storage they are mixed in different layers during the filling up of the granary storage. The effectiveness of the fresh outer bark wood chips are known to discourage insects from feeding on the grain for 3 to 4 months (Musanda Mavhunga, pers. comm.).

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Fresh wood chips extracts discourage insect infestation and, if found not to be effective, dried powdered leaf and fresh outer bark extracts are mixed with grain after thorough inspection (Musanda Mavhunga, pers. comm.). The powdered leaf extracts are believed to attract insects to feed on the extracts rather than on the grain (Musanda Mavhunga, pers. comm.). The powdered extracts from the leaf are known to attract insects to feed on the powdered cluster, causing death after 1 to 2 months of feeding on the extracts (Musanda Mavhunga, pers. comm.). Leaf extracts are mixed and placed inside the grain in the form of a cluster. This is done in order to attract insects to feed on the powdered cluster prepared in such a way that can be easily removed and thrown away when infestation increases (Musanda Mavhunga, pers. comm.). *S. africana* has been recently shown to provide short term storage protection, while attracting insects to the pesticidal plants, despite the claimed repellency (Mvumi *et al.*, 1995; Chikukura *et al.*, 2011).

2.6 Plant extraction using chromatography techniques

Obtaining extracts from plants is an important step in the analysis of plants with possible biological activity. This process entails separation, characterisation and purification of active compounds through the subjection of the extracts to bioassay (Fabricant and Farnsworth, 2001). Drying and grinding of the plant material to obtain a homogenous sample is an operation undertaken to ensure that the potential active constituents are not lost, distorted or destroyed during the preparation of the extract (Fabricant and Farnsworth, 2001).

To obtain bioactive compounds from natural products, different solvent systems are used for extraction since targeted compounds vary from polar to non-polar and to being thermally labile (Cos *et al.*, 2006). Polar solvents, such as methanol, ethanol or ethyl-acetate, are used when extracting hydrophilic compounds, whereas non-polar solvents, such as dichloromethane or a mixture of dichloromethane/ methanol, are used in the extraction of lipophilic labile compounds (Cos *et al.*, 2006).

Plant extracts occur in mixtures of different types of bioactive compounds with different polarities, and the process of identification and characterisation of bioactive compounds is a challenge (Sasidharan *et al.*, 2011). In the isolation of these compounds, different separation techniques, which include Gas Chromatography (GC), Thin Layer Chromatography (TLC) and High Performance Liquid Chromatography (HPLC) could be used to generate chromatograms.

The chromatograms are characterised by multi-component constituents of the internal chemical composition of the prepared extracts. These techniques allow differentiation between novel and known compounds directly from the extracts so that isolation of known

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compounds can be avoided and constituents with novel characteristics are isolated to obtain pure compounds (Sasidharan *et al.*, 2011). Plant extracts need to be separated into constituents so that each component tested for bioactivity is differentiated for the verification of the purity of the isolated active compounds.

Furthermore, compounds can be characterised through the structure determined by various spectroscopic methods, and attempts can be made to define the structure activity relationship of the active compounds (Sasidharan *et al.*, 2011).

High Performance Liquid Chromatography is a very successful analytical technique widely used for the separation of natural products (Cannell, 1998). This technique is regarded for many factors such as high accuracy and precision, versatility of the system, ease of use, compound specificity, ease of sample preparation, rapid analysis time and high sensitivity.

Compounds of interest are purified by the process of separating or extracting the target compound from other compounds using HPLC. Under chromatographic conditions, each compound has a certain characteristic peak that depends on what needs to be separated. The separated chromatographic peaks are closely related to the conditions of samples, such as the proper mobile phase, flow rate, suitable detectors and columns to get an optimum separation that can be chosen by the chromatographer.

For a compound to be identified using HPLC, a detector must first be selected and set to optimal detection settings in the machine, after which a separation assay will be developed. In the process of the assay, a clean peak of the known sample is observed from the chromatograph, and the detected peak should have a reasonable retention time. It must be well separated from extraneous peaks at the detection levels which the assay is performed (Li *et al.*, 2004). The UV detectors offer high sensitivity to naturally occurring compounds encountered because some compounds have UV absorbance at low wavelengths (Cannell, 1998; Li *et al.*, 2004). The high sensitivity of the UV detection is the best result obtained if compounds of interest are present in small amounts within the sample (Cannell, 1998).

2.7 Natural organic fluorine compounds as insecticides

There are approximately 30 known organofluorine compounds as compared to 1850 natural organobromine compounds and 2150 natural organochlorines (Gribble, 2002). Organofluorine compounds are not known to occur naturally (Gribble, 2002; O'Hagan and Harper, 1999). But all of the known biologically produced fluorinated organic compounds are known to contain various aliphatic and aromatic compounds (Key *et al.*, 1997).

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However, some specialised tropical plants are able to metabolise fluorine in their leaves, seeds and roots into producing organofluorine compounds, such as monofluoroacetic acid (MFA), at high concentrations (Key *et al.*, 1997; Gribble, 2002). Other plants can metabolise inorganic fluorine into producing natural fluoroacetates and fluorocitrates, at very low concentration. MFA natural toxic compounds present in plants are known to be lethal when consumed even in small proportions (Key *et al.*, 1997; Murphy *et al.*, 2003).

Organofluorine compounds have been found to have herbicidal, insecticidal, fungicidal and plant growth inhibitor properties. Fluorine compounds, like diflubenzuron, chlorfluazuron, and flufenoxuron, affect insect growth by inhibiting chitin synthesis in the insect (Key *et al.*, 1997). Pyrethroid insecticides containing fluorine compounds have knock down properties on insects. Such compounds are cyfluthrin, flucythrinate, and fluvalinate (Key *et al.*, 1997).

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CHAPTER 3: MATERIALS AND METHOD

3.1 Experimental site

This research study was carried out in the School of Agriculture and School of Mathematics and Natural Science laboratories at the University of Venda in Vhembe District, Limpopo Province, Republic of South Africa. The experiment was laboratory-based and was conducted over a period of two years, starting from October 2012.

3.2 Sources of material: Insects, maize and plant extracts

3.2.1 Collection of plant materials and preparation of extracts

The bark, seeds, roots and leaves of the *Spirostachys africana* were collected in the morning, before flowering, from Mavhunga in South Africa, situated at $22^{0}55'47.57''$ S and $30^{0}05'59.44''$ E. Old mature trees with good bark and exposing their roots above the soil surface were selected and marked. Old matured trees were selected to avoid deforestation and also to conserve maturing trees. Roots and stem bark of the trees were peeled with a sharp knife and axe and then chopped into pieces. Peeling of the outer plant layer was done to remove the poisonous latex milk that can interfere with the extraction process. Fruits and leaves were picked at the same time when the bark and roots were collected. Plate 1 shows the raw materials after collection.

The plant materials were air dried naturally in the laboratory for five to ten days. Plant materials from different parts of the tree were cut into smaller pieces and finely ground to powder in an electric mill (Ultra Centrifugal Mill ZM200). Plate 2 shows the powders which were kept in separate labelled plastic jars with tightly fitting lids. The powder plant materials were then stored and refrigerated at 4 °C before use in bioassays.

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Plate 1. Plant materials collected from *Spirostachys africana*



Plate 2. Powdered material from *Spirostachys africana*

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3.2.2 Maize collection

A total of 6 kg white maize grains to be used for the experiment were collected from Nzhelele at Mauluma Village. Fresh grain, free of insecticides was cleaned to remove weed seeds. It was disinfected by keeping the grain in the freezer at -20 °C for one week in order to kill any hidden infestation before use in the bioassays. The grain was then kept at room temperature for a day to acclimatise.

3.2.3 Culturing of insects

Cultures of *Sitophilus zeamais* were collected from infested stored maize grain in Nzhelele, Vhembe District, and reared on maize. Plate 3 shows infested grain with *S. zeamais*. The maize was chilled for 2-3 minutes to reduce insect mobility. The infested grain was sieved into a bowl covered with nylon mesh to collect the insects. Weevils were introduced into two Kilner jars, each with 500 grams of maize grain, which had been stored for 24 hours in the freezer. Kilner jars were covered with nylon mesh tightened by rubber bands. The adult insects were allowed to mate and oviposit. The cultures of insects were maintained in a laboratory. After four weeks, newly emerged adults were used to establish the main culture which was used for various bioassays.



Plate 3. Maize infested with *Sitophilus zeamais*

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3.3 Effect of plant powder on *S. zeamais*

A total of five treatments comprising of the leaf, seed, outer bark, inner bark and root ground powders were used. Powder from each sample at 0.05, 0.5, 2.5 and 5 g were mixed with 50 g of maize grain in individual 80 plastic jars (500 ml). No plant powder was added to control jars. The plastic jars, with their contents, were gently shaken to ensure a thorough admixture of maize grains and plant powders.

Ten females and 10 males of adult *S. zeamais* were transferred to each plastic jar. Males and females were sexed using a binocular microscope. The jars were laid out in a Complete Randomised Design (CRD) with 5 treatments at 4 concentrations and 4 replicates per treatment. All jars were placed in the laboratory.

The plastic jars were left to stand for specified time periods. After 30, 60 and 90 days, grains from each treatment were re-weighed to determine the percentage loss of grain. Maize weevil mortality was assessed by counting the number of dead and alive insects. Plate 4 shows infested maize grain treated with plant powder being sieved before assessing maize grain weight loss and weevil mortality. Adult weevils were considered dead if, when gently probed with sharp objects, were unable to move or respond.



Plate 4. Sieving infested maize grain treated with plant powder.

Grain weight loss in percentage from each treatment was determined as follows:

$$\% \text{ weight loss} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

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3.4 Extraction of crude extracts from plant materials

Plant powders found to be effective in killing *S. zeamais* were subjected to methanol water extraction. Twenty grams of each plant powder were transferred into 100 ml volumetric flasks and then mixed with 20% water and 80% methanol at room temperature. The mixtures were allowed to settle overnight and then filtered through Whatman No. 1 filter paper. The filtrates were kept in glass vials, and stored at 4 °C until needed for bioassays. The combined methanol and water filtrates were evaporated to give crude extracts. The resulting plant fractions were separated and analysed using High Performance Liquid Chromatography (HPLC), Gas Chromatography (GC) and Gas chromatography–mass spectrometry (GC-MS), in order to determine the active compounds. The resulting plant fractions were then used in bioassays for contact toxicity, repellent effect and feeding deterrent effect against *S. zeamais.*

3.4.1 Contact toxicity by topical application

A sample of 100 *S. zeamais* newly emerged adults (5 days old) were chilled in groups of 5 for 2-3 minutes to reduce their mobility before being transferred into a Petri dish. One µL of each crude extract fraction was applied on the dorsal surface of the thorax of each individual insect using a micropipette. Distilled water was applied as a control. Mortality was recorded at 1 h, 24 h and at 48 h post application. Adult weevils were considered dead when gently probed with sharp objects and were unable to walk or respond. Plate 5 shows the experimental layout of Petri dishes used in the assessment of mortality of weevils by contact toxicity. The experiment was repeated four times.

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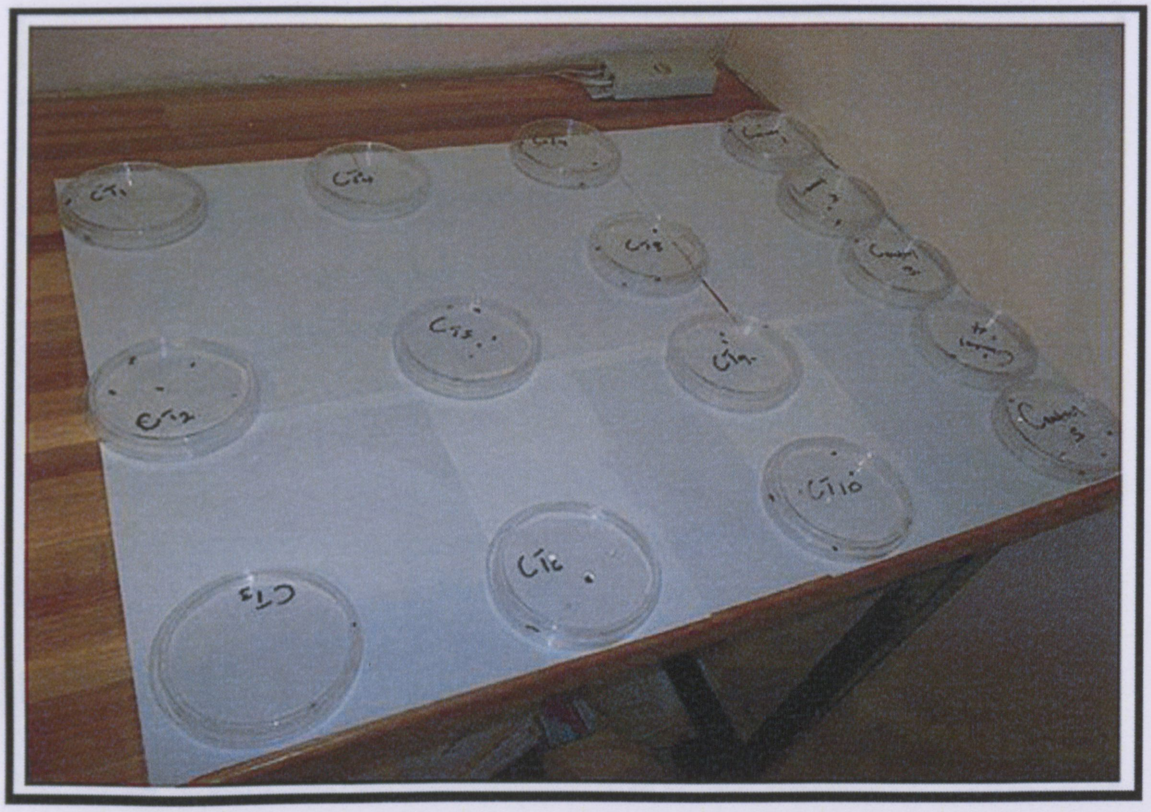


Plate 5. Experimental layout of petri dishes for contact toxicity bioassay.

The percentage mortality was calculated as follows:

$$\% \text{ mortality} = \frac{\text{Number of dead insects in a jar}}{\text{Total number of insects in a jar (dead + alive)}} \times 100$$

3.4.2 Determining repellent effects of crude extracts.

Repellent effects of the fraction were evaluated using the method by McDonald (1970, cited by Babarinde and George, 2008) based on the area of preference and varying degrees. The treatments were prepared by placing the plant fractions onto a 9 cm diameter Whatman filter paper disc cut in half. Untreated and treated filter papers cut in half were placed in a plastic jar with a perforated container. Ten adult insects (1 week old) were released at the centre of each plastic jar mounted with a perforated plastic container and then covered with nylon mesh. Plate 6 shows the experimental layout for repellent effects bioassay. Repellent effects, as presented in Plate 7, were assessed after observation and counting the number of insects crawling to the perforated container and insects remaining on the treated area of the disc. Repellency was recorded after 30 min, 1 h and 4 h after treatment.

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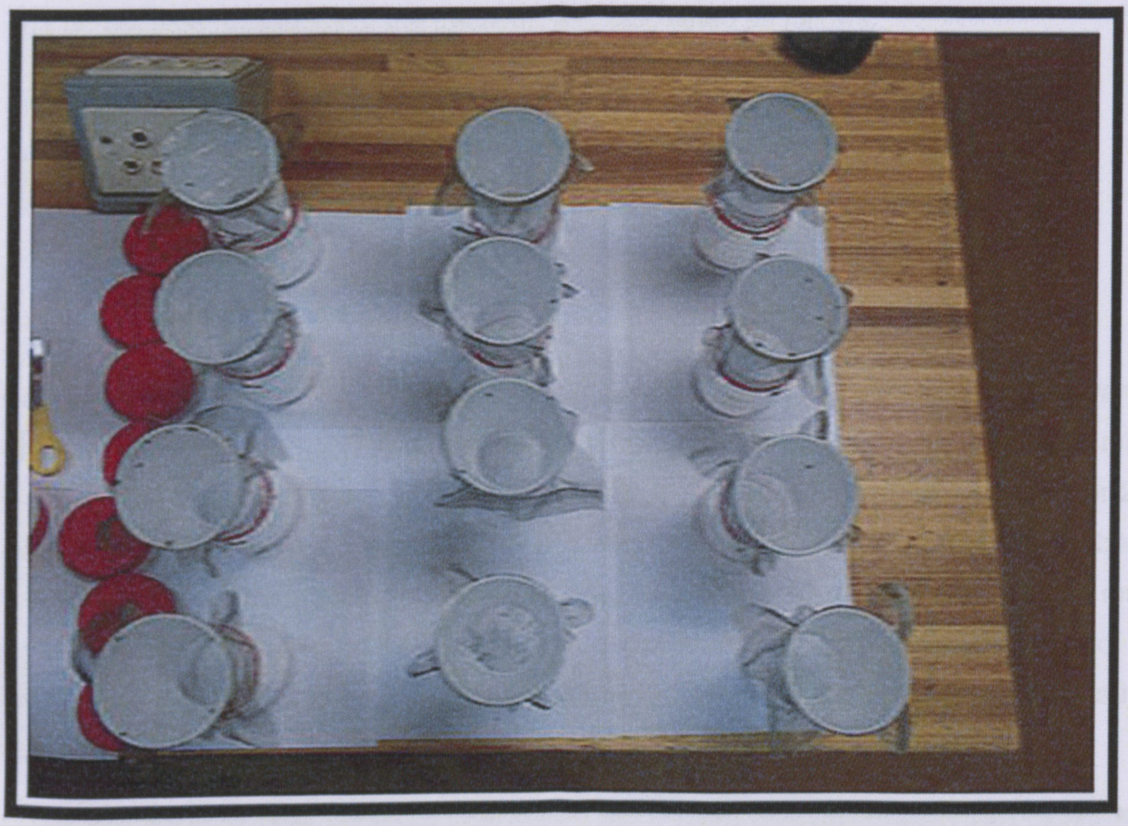


Plate 6. Experimental layout of perforated containers with nylon mesh for repellency bioassays.

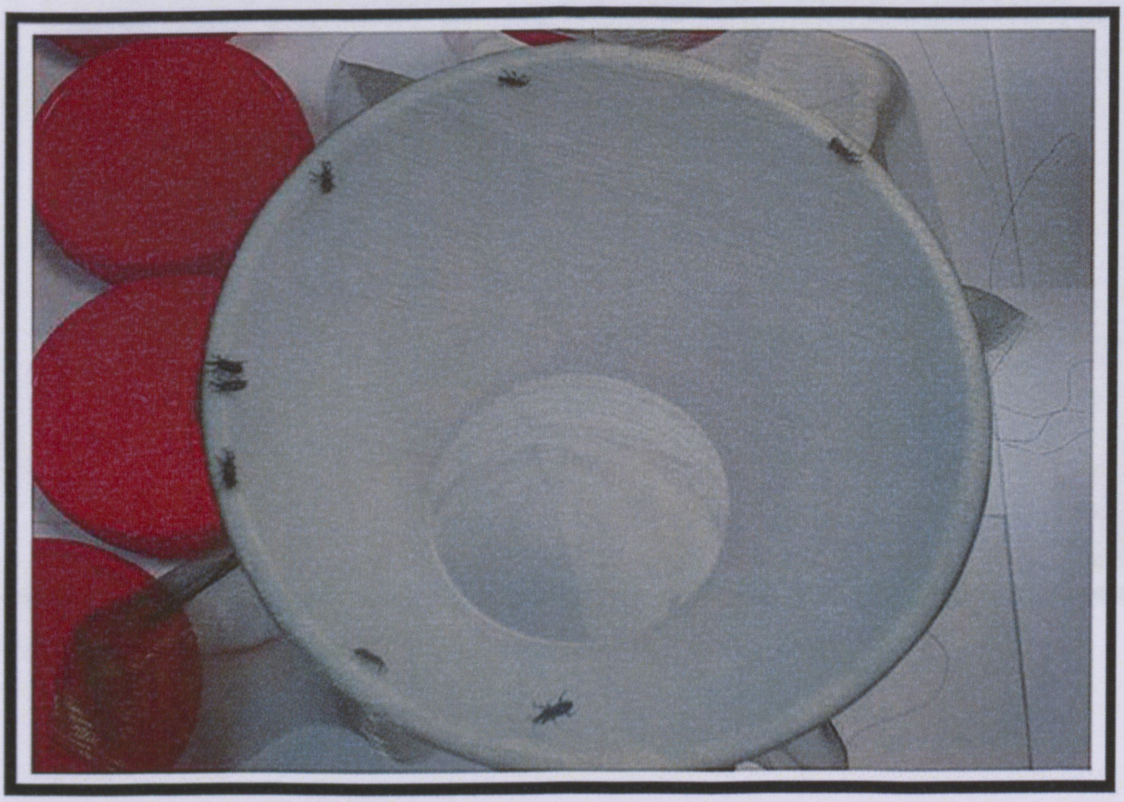


Plate 7. Maize weevil repelled by extracts crawling to the nylon mesh.

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The percentage repellency of the fractions was calculated as follows:

$$\% \text{ repellency} = \frac{\text{Number of insects in the perforated container}}{\text{Total number of insects in the jar}} \times 100$$

3.4.3 Feeding deterrence.

Feeding deterrence of plant fractions was assessed by using plant fractions of varying concentrations of 0.5, 1, 1.5 and 2 ml per 50 g of maize. Maize grain was thoroughly mixed with plant fractions and ten (10) one week-old adult *S. zeamais* previously starved for 24 h were allowed to feed for 7 days. Plate 8 shows the measuring of crude extracts before thoroughly mixing the maize grains by stirring. Plate 9 and 10 show the transfer of maize weevils to maize grains treated with crude extracts and the experimental layout of the feeding deterrence bioassay. Feeding deterrence of the extracts was determined by assessing the number of grains damage caused by the weevil.



Plate 8. Measuring of crude extracts before treating maize grains

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Plate 9. Transfering maize weevils to maize grain treated with crude extracts



Plate 10. Layout of feeding deterrent experiment

The percentage grain damage was calculated as follows:

$$\% \text{ Grain damage} = \frac{\text{Number of bored grains}}{\text{Total number of grains}} \times 100$$

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3.5 Separation and isolation of active ingredients of *S. africana* by High Performance Liquid Chromatography (HPLC)

Extracts of *S. africana* were separated using HPLC and by documenting the chromatogram. The HPLC analysis was performed using a Perkin Elmer 200 series HPLC system with 200 series Diode array detector, 200 series column oven, a 200 series auto sampler and 200 series pump (Perkin Elmer, C18, 250 X 4.6 mm). To prepare the HPLC for separation, three different concentrations of eluents were prepared as 10% acetone, 80% methanol and deionised water. All eluents were degassed by bubbling inert nitrogen gas into all eluent bottles to remove dissolved gases.

The HPLC analysis was prepared following the methods used by Arshi *et al.* (2011). A water µporasil column (P/N 27477) was used. The HPLC injection volume was 10 µl and pump pressure was 1600 PSI at a flow rate of 1 ml/min. The degassed mobile phase consisted of 5% acetone, 75% pure deionised water from a Millipore water machine at a conductivity of 0.054µs, and 20% methanol. The analysis time was 15 min at a sampling rate of 2.272 Pts/s. The samples filtrate volume of 10µl was injected into HPLC system as shown in Table 1.

Table 1. HPLC Analysis

Flow rate (ml/min)	Pump pressure (psi)	Eluent composition (%)	Injection volume (µl)	Running time (min)	Sampling rate (pts/s)
1	1600	75% H2O,20% MeOH, 5% CH3COCH3	10	15	2.272

The filtrates were concentrated by using a µP Vacutec Freeze Dryer machine coupled with Alcatel Pascal 2010 SD PUMP because the freeze dryer machine operates at low pressure vapour and low temperature to preserve the chemical composition or chemical structure of the filtrate. The maximum absorbance of the corresponding UV spectra was 254 nm.The injection was repeated with the concentrated filtrate from a freeze dryer, and best separated signals were obtained. Manual collection of different separated compound fractions was carried out and used for various bioassays.

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3.6 Purity of compounds in collected fractions

Fractions of *S. africana* crude extracts were analysed using Gas Chromatography (GC) to identify and to record chromatograms of pure compounds. The analysis was carried out following the method of Pavia *et al.* (2006). The GC analysis was performed using Perkin Elmer Clarus 500 system with Hewitt Packard ultra 1 methyl silicone capillary column of 50 m × 0.2 mm, with a phase thickness of 0.33 µm. The temperature programme for the analyses were as follows: The initial temperature was 100 °C for 4 min. This was increased to 200°C at 3°/min and maintained at a temperature of 260 °C for 3 min. Nitrogen was the carrier gas. Samples of 5 µl of plant fraction were injected into the GC for analysis. The percentage compositions of compounds were obtained from electronic integration measurements using flame ionization detection. The contents of each individual compound were used as reference points in the calculation of relative retention indices (RRI).

3.7 Identification of compounds in collected crude extracts using GC-MS

GC-MS analyses were used to determine the compositions of *S. africana* root and outer bark fractions. The analysis was carried out following the method of Tapondjou *et al.* (2005). Helium (100.0000%) was used as the carrier gas and maintained at a flow rate of 1 ml/min, in a split/split less flow. The electron impact ionization conditions were: ion energy 70 eV, and the mass range scanned was 38 to 650 amu in the full acquisition mode. The column and column temperature programme were the same as those used in GC analyses. *S. africana* fraction constituents were identified by visual comparisons of the mass spectrum of the substance with those of libraries (Wiley and NIST). The identities of components were confirmed by both mass spectral and retention data of the authentic chemicals obtained under identical GC-MS conditions.

3.8 Data analysis

Data generated from biological studies were analysed using analysis of variance (ANOVA) and significant different treatments were separated at 0.05% level of probability by LSD test.

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CHAPTER 4: RESULTS OF BIOLOGICAL STUDIES

4.1 Introduction

The present study was undertaken, in order to evaluate the effect of powders from leaves, seeds, root, outer bark and inner bark of *S. africana* on the biology of *S. zeamais*. The toxicity and feeding deterrent effects of the powders against *S. zeamais* were determined at three storage intervals of 30, 60, and 90 days. Plant powders effective in killing maize weevils were extracted, separated and analysed, in order to determine the active compounds. Plant crude extracts were bioassayed for contact toxicity, repellent effect and feeding deterrent effect against *S. zeamais.*

4.2 Toxicity of *S. africana* powders against *S. zeamais* at 30, 60 and 90 days post treatment.

Toxicity of five *S. africana* powders (leaves, seeds, root, outer bark and inner bark) at three storage periods were evaluated and data were collected on mortality and progeny adult emergence of *S. zeamais*, as well as grain weight loss.

4.2.1 Effect of *S. africana* powders against *S. zeamais* infestation on maize grain at 30 days post treatment

Mean percent mortality was calculated for each of the powders at different dosage rates. Figure 1 shows the mortality data. At a dosage of 0.05 g powders/ 50 g maize, the highest mortality was 63.8% from root powders and this mortality was significantly higher than that of the other four powders. Mortality from leaf powders and outer bark were the next highest (36% and 32%) and did not differ from each other but were significantly higher than mortalities from seed powders (14%) and inner bark (6%). Mortality from inner bark was the lowest and differed significantly from all the other powders. The control mortality (4%) was significantly lower than that of all the other treatments.

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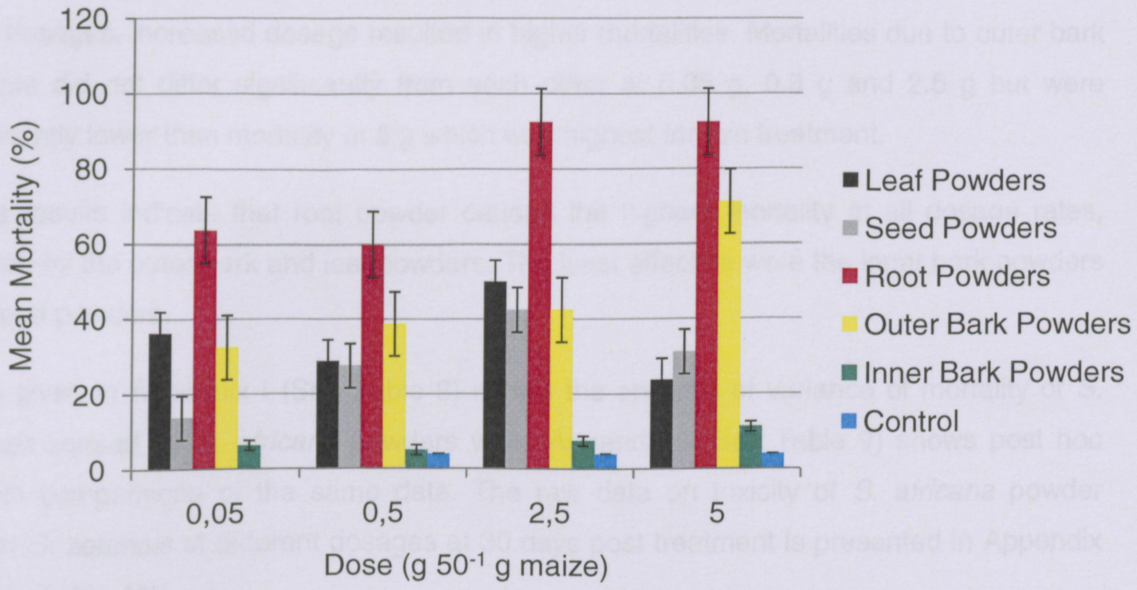


Figure 1. Mortality of *S. zeamais* adults exposed to varying doses of *S. africana* powders at 30 days post treatment

Powders tested at 0.5 g dosage showed a significantly high mortality of 60% from root powders followed by 38.8% from outer bark powders. Mortalities due to outer bark (38.8%), leaf (28.8%) and seed powder (27.5%) were significantly lower than that of root powders, but did not differ significantly from each other. However, all these mortalities were significantly higher than mortality from the inner bark powders. The control mortality (4%) was significantly lower than that of all other treatments.

At a dosage of 2.5 g, the highest mean mortality was 92.5% from root powders and this mortality was significantly higher than that of the other four powders. Mortality from leaf powders (50%), outer bark (42.50%) and seed powders (42.50%) did not differ significantly from each other, but were significantly higher than mortality from inner bark powder (7.5%). The control mortality (4%) was significantly lower than that of all the other treatments.

Powders tested at a dosage of 5 g showed a mortality of 92.5% from root powders which was significantly higher than that of the other four powders. Mortality from outer bark powders (71.3%) was the second highest and was significantly higher than that of the other three powders. Mortalities that did not differ significantly from each other were those from the leaf (23.8%) and seed powders (31.3%) but were significantly different from inner bark powders (11.3%). The control mortality (4%) was significantly lower than that of all the other treatments.

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For root powders, there was no significant difference between 2.5 g and 5 g, while for all other dosages, increased dosage resulted in higher mortalities. Mortalities due to outer bark powders did not differ significantly from each other at 0.05 g, 0.5 g and 2.5 g but were significantly lower than mortality at 5 g which was highest for this treatment.

These results indicate that root powder caused the highest mortality at all dosage rates, followed by the outer bark and leaf powders. The least effective were the inner bark powders and seed powders.

[Data given in Appendix I (See Table 8) shows the analysis of variance of mortality of *S. zeamais* caused by *S. africana* powders while Appendix I (See Table 9) shows post hoc multiple comparisons of the same data. The raw data on toxicity of *S. africana* powder against *S. zeamais* at different dosages at 30 days post treatment is presented in Appendix VII (See Table 40)].

4.2.2 Effect of *S. africana* powders on mortality of *S. zeamais* at 60 days post-treatment.

Figure 2 shows the calculated data of mean percent mortality of *S. zeamais* caused by *S. africana* powders at different dosage rates. Control mortality (42.2%) was the lowest and differed significantly from *S. africana* powder treatments.

At a dosage of 0.05 g powders/ 50 g maize, the highest mortality was 87.6% from seed powders and did not differ significantly from leaf powders (79%) and inner bark powders (78.3%). Mortalities from the outer bark powders (74.5%) and root powders (72.4%) were the lowest and did not differ significantly from each other.

Powders tested at a dosage of 0.5 g showed that the highest mortality was 88.2% from seed powders and this mortality was significantly higher compared to that of the outer bark, inner bark and leaf powders, but did not differ significantly from that of the root powders.

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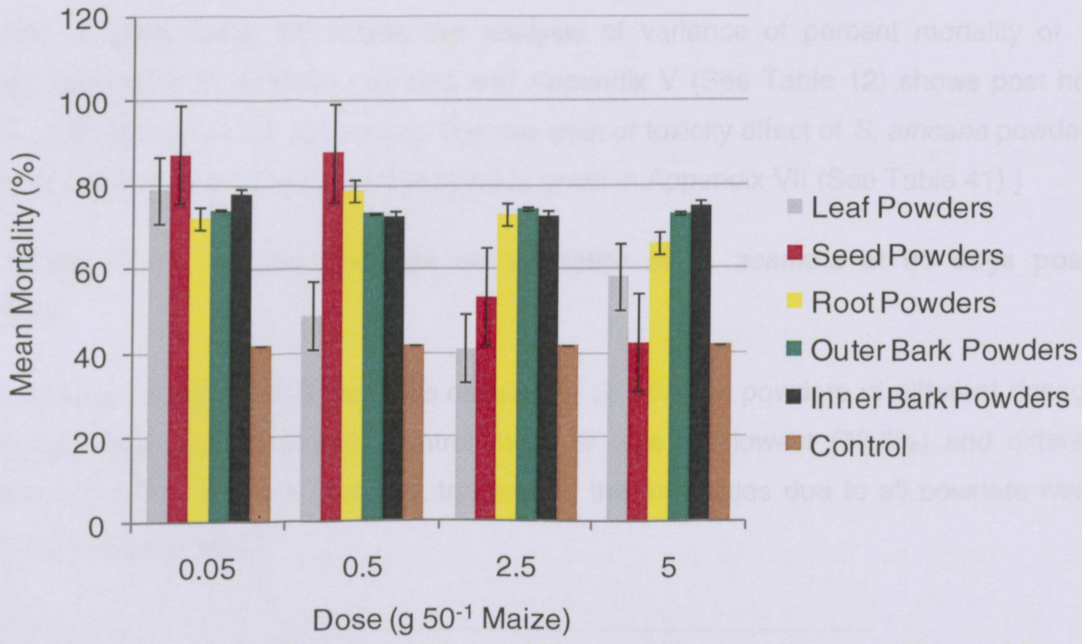


Figure 2. Mortality of *S. zeamais* adults exposed to varying doses of *S. africana* powders at 60 days post treatment

At a dosage of 2.5 g, the highest mortalities were from outer bark powders (74.6%), root (73.4%) and inner bark (72.8%) and those mortalities were significantly higher than those of seed powders (53.7%) and leaf powders (41.6%) which did not differ significantly from each other.

S. africana powders tested at a dosage of 5 g showed that the highest mortality of 75.1% was from inner bark powders and outer bark powders (73.45%) and those did not differ significantly from each other. Mortalities from root powders (66.3%) and leaf (58.4%) were the next highest and did not differ significantly from each other, but differed significantly from seed powders with the lowest mortality of 42.5%.

Mortalities from seed powders were similar at 0.05 g and 0.5 g but were significantly lower at the two other rates. Mortality due to leaf powders varied being highest at 0.05 , decreasing at 0.5 g and 2.5 g to increasing at 5 g. Mortality from root powders, outer bark and inner bark remained constant at all dosage rates.

Results indicate similar mortalities at all dosage rates for root powders, outer bark powders and inner bark powders. Seed powders caused the highest mortality but decreased at other high dosage rates, followed by leaf powders. The least effective treatment was seed powders at the highest two dosages rates.

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[Appendix V (See Table 10) shows the analysis of variance of percent mortality of *S. zeamais* caused by *S. africana* powders and Appendix V (See Table 12) shows post hoc multiple comparisons of the same data. The raw data of toxicity effect of *S. africana* powders against *S. zeamais* at 60 days post treatment is given in Appendix VII (See Table 41).]

4.2.3 Effect of *S. africana* powders on mortality of *S. zeamais* at 90 days post-treatment.

Figure 3 shows mortality of *S. zeamais* caused by *S. africana* powders at different dosage rates at 90 days post treatment. Control mortality was the lowest (72.6%) and differed significantly from *S. africana* powders. In general, the mortalities due to all powders were similar at all dosage rates.

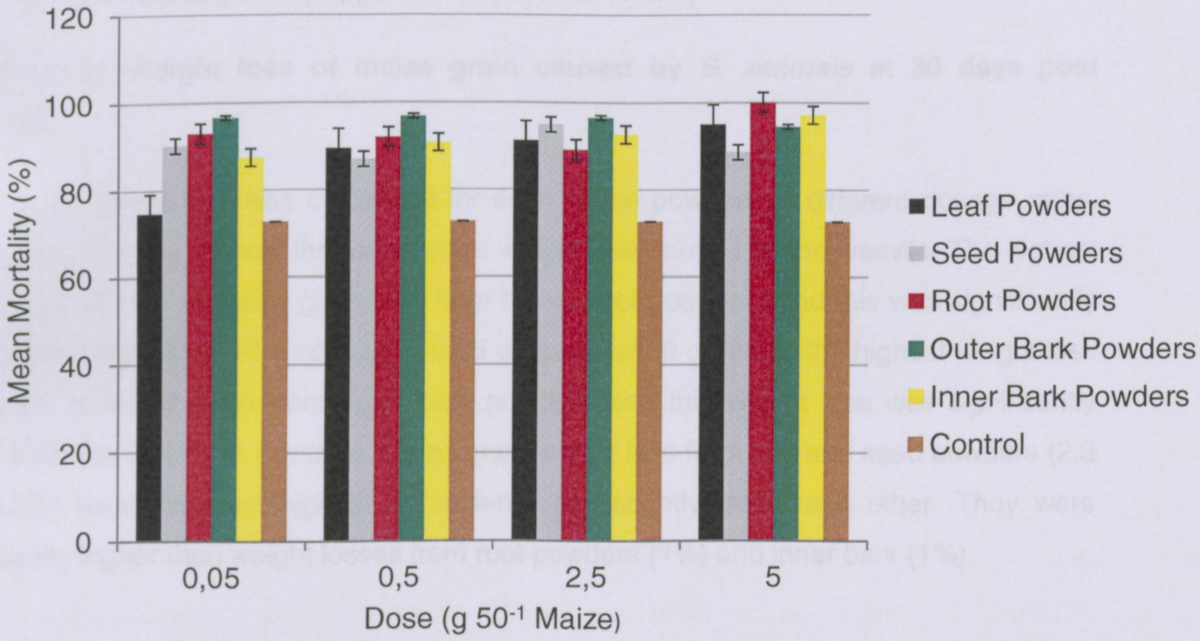


Figure 3. Mortality of *S. zeamais* adults exposed to varying doses of *S. africana* powders at 90 days post treatment

Powders at a dosage of 0.05 g/ 50 g maize showed the highest weevil mortalities from outer bark powders (96.5%), root (92.9%) and seed (90.3%) and their mortalities were significantly higher than those of leaf powders but did not differ from each other. Mortality from inner bark powders (87.45%) were the next highest and those were significantly higher than those of leaf powders (74.7%) which were the lowest.

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At a dosage of 0.5 g and 2.5 g mortalities due to all powders did not differ significantly from each other.

At the highest dosage of 5 g, the highest weevil mortality was 100% from root powders, but this mortality did not differ significantly from that of leaf powders, outer bark and inner bark. Mortality from seed powders showed the lowest mortality of 88.6%. At 90 days post-treatment, all powders gave good control of the weevils.

These results show that all *S. africana* powders caused high mortalities at all dosage rates, giving good control of the weevils.

[Information given in Appendix V (See Table 11) shows the analysis of variance of mortality of *S. zeamais* caused by *S. africana* powders and Appendix V (See Table 13) shows post hoc multiple comparisons of the same data. Raw data of toxicity effect of plant powder at 90 days post treatment is given in Appendix VII (See Table 42).]

4.2.4 Percent Weight loss of maize grain caused by *S. zeamais* at 30 days post treatment

Maize grain weight loss was calculated for each of the powders at different dosage rates. Data given in Figure 4 show the maize grain weight loss caused by the weevils. The highest weight loss of 14% of maize grain was from the control treatment and this was significantly the highest weight loss. At a dosage of 0.05 g powders/ 50 g maize, the highest weight loss was 6.8% of maize grain from outer bark powders and this weight loss was significantly higher than the other four powders. Maize grain weight loss from leaf and seed powders (2.3 and 3.3%) were the next highest but differed significantly from each other. They were significantly higher than weight losses from root powders (1%) and inner bark (1%).

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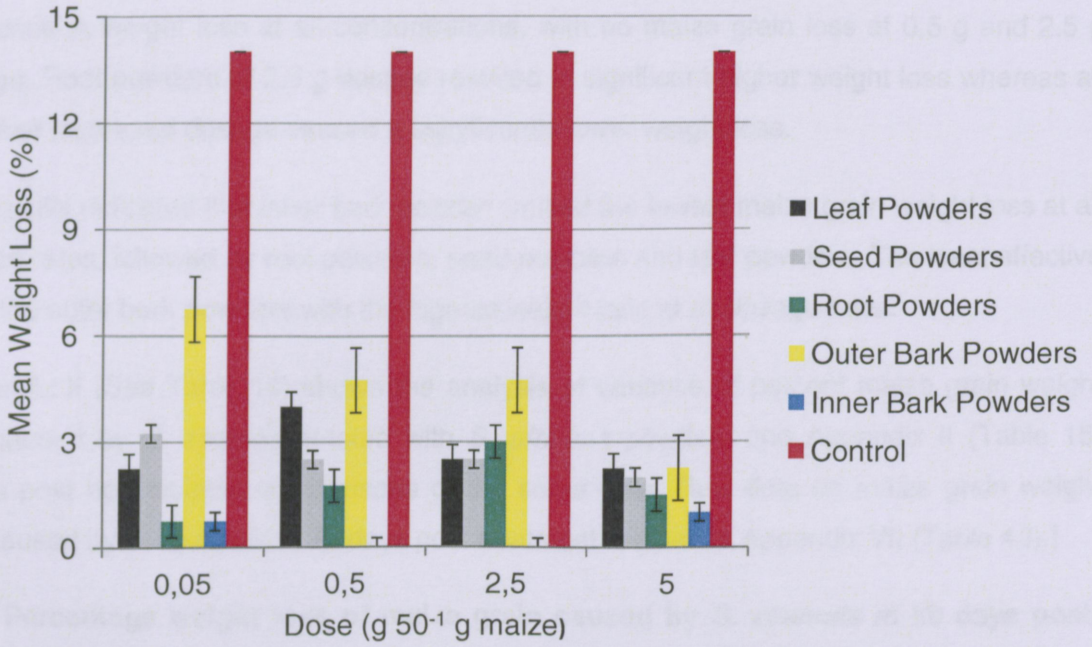


Figure 4. Maize grain weight loss caused by *S zeamais* treated with *S. africana* powders in varying doses at 30 days post treatment

At a dosage of 0.5 g, the highest weight loss was recorded for by outer bark powders (4.8%) and leaf powders (4%), and their weight loss did not differ significantly from each other. Maize grain weight loss from root (1.8%) and seed powders (2.5%) were the next highest and differed significantly from each other. There was no maize grain weight loss from inner bark powders.

Powders tested at 2.5 g showed a significantly higher weight loss of 4.8% from outer bark powders as compared to the other powders. The second highest weight loss was from root powders (3%), followed by leaf powders (2.5%) and seed (2.5%), which did not differ significantly from each other. Inner bark powders showed no maize grain weight loss.

Maize grain weight loss at the application of 5 g powders/ 50 g maize showed weight loss from leaf powders (2.3%), outer bark (2.3%), seed (2%) and root (1.5%) and these weight losses did not differ significantly from each other. Maize grain weight loss of 1% was from inner bark powders and this was significantly lower compared to the other powders and the control.

Maize grain weight loss due to application of outer bark powders at 0.05 g dosage resulted in significantly higher maize grain weight loss followed by seed and leaf powders while all the other increased dosages resulted in significantly lower weight loss. For leaf powders, there was a significantly higher weight loss at 0.5 g dosage, whereas all the other increased

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dosages resulted in significantly lower weight loss. Inner bark powders showed no significant difference in weight loss at all concentrations, with no maize grain loss at 0.5 g and 2.5 g dosage. Root powders at 2.5 g dosage resulted in significant higher weight loss whereas all the other increased dosage caused a significantly lower weight loss.

The results indicated that inner bark powder caused the lowest maize grain weight loss at all dosage rates, followed by root powders, seed powders and leaf powders. The least effective were the outer bark powders with the highest weight loss at all dosage rates.

[Appendix II (See Table 14) shows the analysis of variance of percent maize grain weight loss caused by *S. zeamais* treated with *S. africana* powders and Appendix II (Table 15) shows post hoc multiple comparisons of the same data. Raw data on maize grain weight loss caused by *S. zeamais* at 30 days post treatment is given in Appendix VII (Table 43).]

4.2.5 Percentage weight loss of maize grain caused by *S. zeamais* at 60 days post-treatment

Mean percent maize grain weight loss calculated for each of the powders at different dosages is given in Figure 5. Maize grain weight loss from control treatment (30.1%) was the highest and was significantly higher compared to all the *S. africana* powder treatments.

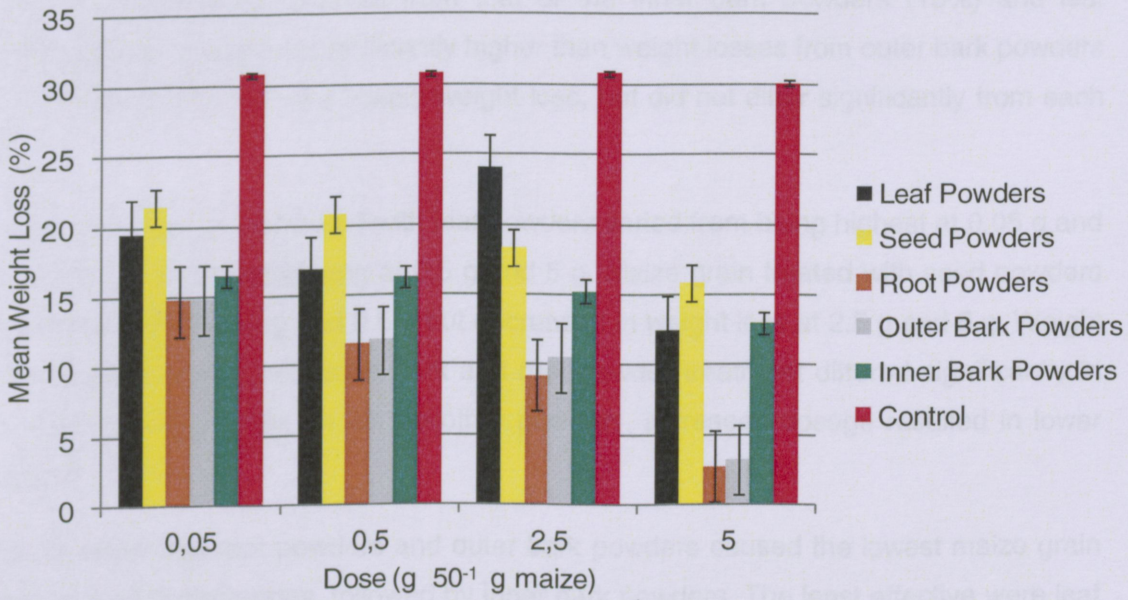


Figure 5. Maize grain weight loss caused by *S. zeamais* treated with *S. africana* powders in varying doses at 60 day post treatment

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Powders tested at a dosage of 0.05 g/ 50 g maize showed that the highest maize grain weight losses were from seed powders (21.5%) and leaf powders (19.5%) and that these weight did not differ from each other. The third highest maize grain weight loss was from the inner bark (16.5%) but it was not significantly different from weight losses from outer bark powders (14.8%) and root (14.6%). Inner bark, root and outer bark powders did not differ significantly.

At a dosage of 0.5 g, the highest maize grain weight loss was 20.8% from seed powders, and this weight loss was significantly higher than that of the other four powders. The second highest weight loss was from leaf powders (16.9%) and then inner bark (16.3%) which did not differ significantly from each other, but differed significantly from weight losses from outer bark (11.8%) and root (11.5%).

Powders tested at 2.5 g showed that the highest maize grain weight loss was 24% from leaf powders and this weight loss was significantly higher than that of the other four powders. The second highest weight loss was from seed powders (18.3%), followed by inner bark (18.25%) and their weight loss did not differ significantly from each other. Weight loss from outer bark powders (10.5%) and root (9.3%) did not differ significantly from each other.

At a dosage of 5 g, the highest weight loss was 15.8% from seed powders and this weight loss was not significantly different from that of the inner bark powders (13%) and leaf (12.5%). However, they were significantly higher than weight losses from outer bark powders (3.2%) and root (2.7%) with the lowest weight loss, but did not differ significantly from each other.

Weight loss of maize grain treated with leaf powders varied from being highest at 0.05 g and increasing at 2.5 g but decreasing at 0.5 g and 5 g. Maize grain treated with seed powders remained constant at 0.05 g and 0.5 g but decreased in weight loss at 2.5 g and 5 g. Weight loss due to seed, inner bark, outer bark and root powder treatment differed significantly in weight loss at 0.05 g, while for all the other powders, increased dosage resulted in lower weight loss.

The results show that root powders and outer bark powders caused the lowest maize grain weight loss at all dosage rates, followed by inner bark powders. The least effective were leaf powders and seed powders with the highest weight losses.

[Data shown in Appendix IV (See Table 16) show analysis of variance for maize grain weight loss caused by *S. zeamais* at 60 days post treatment and Appendix IV (See Table 18) shows post hoc multiple comparisons of the same data. The raw data of maize grain weight loss

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caused by *S. zeamais* at 60 days post treatment is presented in Appendix VII (See Table 44).]

4.2.6 Percentage weight loss of maize grain caused by *S. zeamais* at 90 days post treatment.

At 90 days post treatment mean weight loss of maize grain was calculated for each of the powders at different dosage rates. Figure 6 shows the weight loss data. The highest significantly different maize grain weight loss was from control treatment (48.6%) and this weight loss was different compared to *S. africana* powders treatments.

At a dosage of 0.05 g powders/ 50 g maize, the highest weight loss was 37.5% from inner bark powders, and this weight loss was significantly higher compared to the other four powders. The next highest weight loss was from seed powders (29%), root powders (26.5%) and outer bark powders (26.5%) which did not differ from each other. The lowest weight loss of 24.5% was from leaf powders.

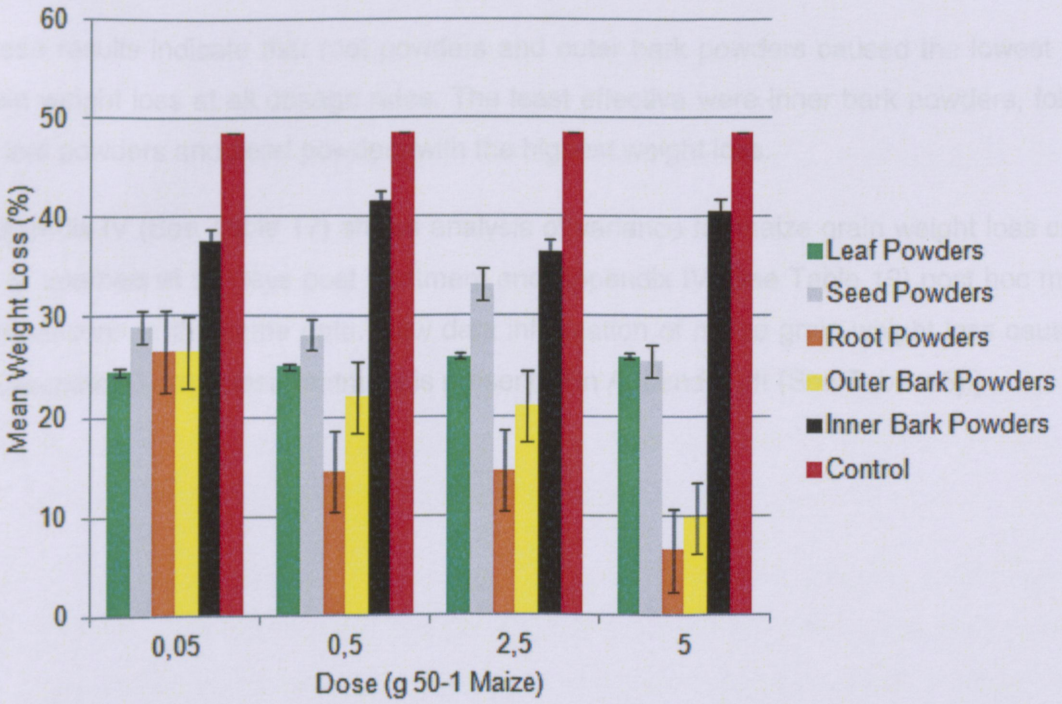


Figure 6. Maize grain weight loss caused by *S. zeamais* treated with *S. africana* powders in varying doses at 90 day post treatment

All powders tested at 0.5 g differed significantly from each other. The highest maize grain weight loss of 41.5% was from inner bark powders, followed by seed powders (28.3%) and leaf (25%), outer bark powders (22%) and root (14.5%).

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At a dosage of 2.5 g, all powders differed significantly from each other. The highest maize grain weight loss was from inner bark powders (36.5%) and seed (33.25%) followed by loss from leaf powders (26%) and outer bark (21%). Loss from root powders (14.5%) was the lowest.

At the highest dosage of 5 g powders, the highest weight loss was 40.5% from the inner bark, which was significantly higher than that of all the other powders. The second highest weight loss was from leaf powders (26%) and seed powders (25.5%) and their weight loss did not differ significantly from each other. Weight losses from outer bark powders (9.8%) and root powders (6.5%) were lowest, and they did not differ significantly from each other.

Grain weight loss from maize treated with inner bark powders was consistently higher than that of all the other powders at all dosage rates. For seed powders, there was significant difference in weight loss at 2.5 g dosage, while for all the others increased dosage resulted in lower maize weight loss. Grain loss from leaf powders was constant at all dosage rates. Weight losses of maize treated with outer bark and root powders generally decreased with increased dosage rates.

These results indicate that root powders and outer bark powders caused the lowest maize grain weight loss at all dosage rates. The least effective were inner bark powders, followed by leaf powders and seed powders with the highest weight loss.

[Appendix IV (See Table 17) shows analysis of variance for maize grain weight loss caused by *S. zeamais* at 90 days post treatment and Appendix IV (See Table 19) post hoc multiple comparisons of the same data. Raw data information of maize grain weight loss caused by *S. zeamais* 90 days post treatment is presented in Appendix VII (See Table 45).]

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4.2.7 Effect of *S. africana* on adult emergence of *S. zeamais* at 60 days post treatment.

The mean number of *S. zeamais* adults that emerged indicates that a significantly higher number of adult weevils emerged in the control treatment (43.88%) when compared with *S. africana* powder treatments. Figure 7 shows the data for adult beetle emergence.

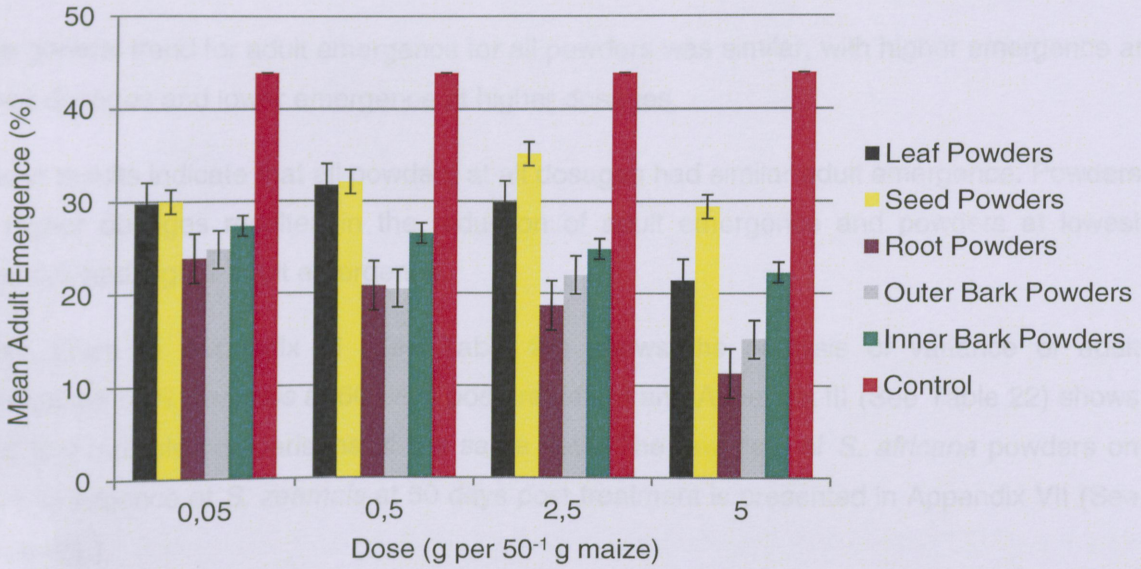


Figure 7. Effect of *S. africana* powders on adult emergence of *S. zeamais* at 60 day post treatment

The highest number of adult weevil emergence was from the control treatment. At a dosage of 0.05 g powders/ 50 g maize, the adult weevil emergence from leaf powders (29.9%) and seed and (29.8%) did not differ significantly from each other, but was significantly higher compared to the other powders. Adult weevil emergence from root powders (23.8%) outer bark (24.8%) and inner bark (27.8%) did not differ significantly from each other.

Adult weevil emergence at 0.5 g powders/ 50 g maize showed a higher adult emergence from seed powders (32.1%) and leaf (31.8%) but these did not differ significantly from each other, but were significantly higher compared to the other powders. Adult emergence from inner bark powders was 26.5% and this was significantly higher than adult emergence from outer bark (20.5%) and root (20.8%), which did not differ significantly from each other.

At a dosage of 2.5 g, the highest emergence of weevils was 35.2% from seed powders, followed by leaf powders (29.9%) and these differed significantly from each other. Adult emergence from inner bark (24.83%) and outer bark (22%) did not differ significantly from each other, but differed from root (18.7%) which had the lowest emergence rate.

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Powders applied at a dosage of 5 g / 50 g maize showed significantly different adult emergences from each other, with the highest of 29.4% from seed powders followed by inner bark powders (22.3%) and leaf (21.4%). However these did not differ from each other but were significantly higher than adult emergence from outer bark (15%) and root (11.3%). Adult emergence from root was the lowest and differed significantly from all the other powders.

The general trend for adult emergence for all powders was similar, with higher emergence at lower dosages and lower emergence at higher dosages.

These results indicate that all powders at all dosages had similar adult emergence. Powders at higher dosages resulted in the reduction of adult emergence and powders at lowest dosages had higher adult emergence.

[Data given in Appendix III (See Table 20) shows the analysis of variance of adult emergence of *S. zeamais* at 60 days post treatment and Appendix III (See Table 22) shows post hoc multiple comparisons of the same data. The raw data of *S. africana* powders on adult emergence of *S. zeamais* at 60 days post treatment is presented in Appendix VII (See Table 46).]

4.2.8 Effect of *S. africana* on adult emergence of *S. zeamais* at 90 days post treatment.

Figure 8 shows data of *S. zeamais* adult emergence after 90 days post-treatment. The highest number of adult weevil emergence was from the control treatment. At 0.05 g/ 50 g, adult emergences were not significantly different among seed powders (83.3%), root powders (81.8%) and inner bark powders (89.5%).

At 0.5 g, the highest emergence was from seed powders (87.3%) and inner bark powders (87.8%), and these did not differ significantly from each other. The next highest emergence was from leaf powders (69.8%) which differed significantly from the lower emergences from outer bark (61%) and root (55.25%).

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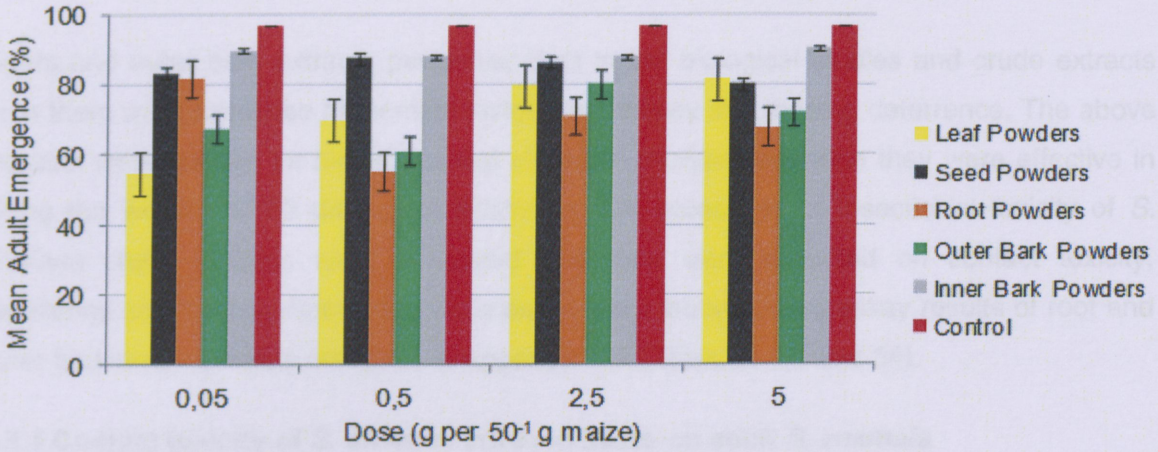


Figure 8. Effect of *S. africana* powders on adult emergence of *S. zeamais* at 90 days post treatment

At 2.5 g and 5 g, the adult emergences from all powders were not significantly different from each other.

In general, adult emergence from seed powders and inner bark powders, at all dosage rates, did not differ significantly from each other. There was some variation in emergence rates for root powders, being higher at 0.05 g, decreasing at 0.5 g, picking up again slightly at 2.5 g and 5 g. The emergence from leaf powders was low at 0.05 g, but did not differ significantly from the other three rates. Emergence from outer bark was similar at 0.05 g and 0.5 g; and again at the two higher rates.

Inner bark powders and seed powders resulted in high adult emergences showing that they were the least effective in controlling weevils. These were followed by leaf powders. The most effective in reduction of adult emergence were root powders and outer bark powders which had lower emergence values.

[Appendix III (See Table 21) shows the analysis of variance of adult emergence of *S. zeamais* at 90 days post treatment and Appendix III (See Table 23) shows post hoc multiple comparisons of the same data. Raw data information of adult emergence at 90 days post treatment is presented on Appendix VII (See Table 47).]

Effective treatments in terms of mortality and grain weight loss were experienced over 30 day post-treatment. All powders were effective in controlling the weevils but root powder caused the highest mortality, followed by the outer bark. Among other treatments inner bark powders caused the lowest grain weight loss followed by root powders. Root and outer bark powders were subjected to chromatography experiments as they were found to be effective in killing the weevils.

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4.3 Laboratory bioassay studies of *S. africana* crude extracts

Roots and outer bark extracts performed best in the biological studies and crude extracts from them were assessed for contact toxicity, repellency and feeding deterrence. The above extracts were chosen for bioassays and chemical analyses because they were effective in killing the weevils at 30 days post treatment. The bioassays of insecticidal toxicity of *S. africana* crude extracts were evaluated and data were collected on contact toxicity, repellency and feeding deterrence. Raw data for the laboratory bioassay results of root and outer bark crude extracts are given in Appendix VIII (Table 48 – Table 54).

4.3.1 Contact toxicity of *S. africana* crude extracts on adult *S. zeamais*

Toxicity of the root crude extracts applied topically to *S. zeamais* is summarised in Table 2. The results show mean mortalities caused by *S. africana* crude extracts at three different time points for data collected in four observations. Mortality results were calculated after probing the weevils with sharp objects. The weevils were considered dead if unable to move and respond. The highest mean mortality of 56% was observed in root extracts 48 h after treatment, while the lowest mortality was 6% after 1 h.

Table 2. Mortality (%) due to root crude extracts applied topically (contact toxicity) to *S. zeamais*

Root crude extracts	**[Time (minutes)]**		
Experiment	**1 h**	**24 h**	**48 h**
1	18 ± 12.02 [a]	38 ± 19.44 [a]	56 ± 17.32 [a]
2	6± 6.66 [c]	20 ± 16.32 [b]	32 ± 25.29 [c]
3	10 ± 19.44 [d]	10 ± 14.14 [c]	16 ± 15.78 [d]
4	22 ± 11.55 [a]	36 ± 9.57 [a]	38 ± 11.55 [b]
Overall Mean	**14 ± 12.42**	**26 ± 14.87**	**35.5 ± 17.49**

Mean (±SE) within a column followed by the same letter are not significantly different (LSD test, $P<0.05$)

There was no control mortality in all treatments at all time points. Mortalities ranged widely at each time point. At 1 h post treatment, mortalities ranged from 6% to 22%, with a mean of 14%. At 24 h, the range was 10% to 38%, with a mean of 26%. At 48 h, the range was 16% to 56%, with a mean of 35.5%.

Mortalities due to outer bark crude extracts applied topically are summarised in Table 3. The highest mortality of 44% was after 48 h post treatment, while the lowest mortality of 4% was after 1 h.

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Table 3. Mortality (%) due to outer bark crude extracts applied topically (contact toxicity) to *S. zeamais*

Outer bark crude extracts	[Time (minutes)]		
Experiment	**1 h**	**24 h**	**48 h**
1	4 ± 13.49 [b]	6 ± 8.16 [b]	12 ± 8.17 [c]
2	24 ± 9.57 [a]	34 ± 9.57 [a]	40 ±17.08 [a]
3	24 ± 9.57 [a]	34 ± 12.91 [a]	44 ± 12.58 [a]
4	22 ± 8.16 [a]	36 ± 16.33 [a]	32 ± 5.00 [b]
Overall Mean	**17.5 ± 10.19**	**26 ± 11.74**	**32 ± 10.88**

Mean (±SE) within a column followed by the same letter are not significantly different (LSD test, P<0.05)

Weevil mortalities ranged widely at each time point. At 1 h post-treatment, mortalities ranged from 4% to 24%, with a mean of 17.5%. At 24 h, the range was 6% to 36%, with a mean of 26%. At 48 h, the range was 12% to 44%, with a mean of 32%.

Figure 9 shows the graphical presentation of *S africana* crude extracts applied topically on *S. zeamais* and assessed after three different exposure periods.

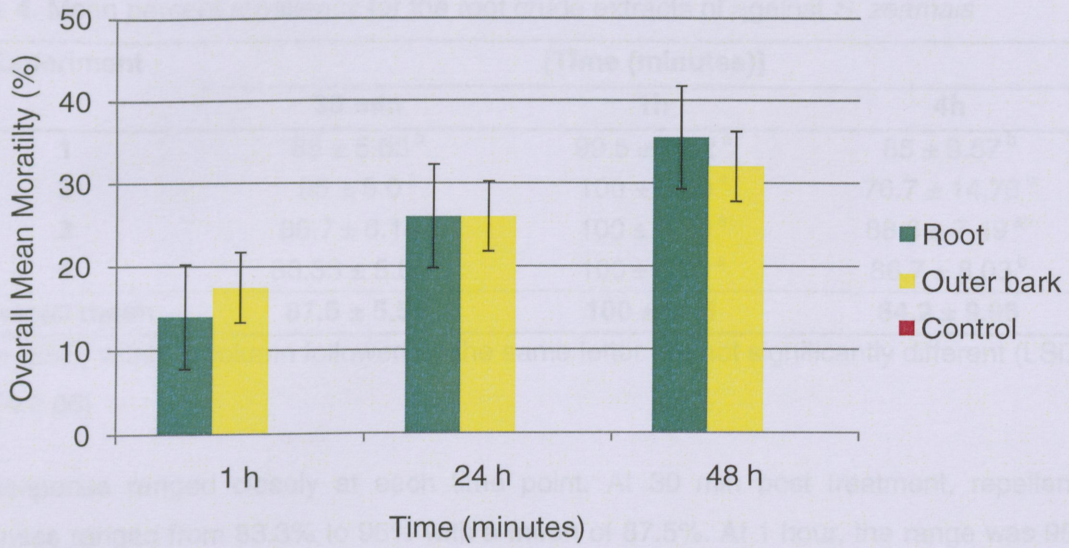


Figure 9. Mean mortality of adult *S. zeamais caused* by *S. africana* crude extracts

Mortalities from both extracts were similar at each time point, but were significantly lower at 1 h point. Extracts causing mortalities to the weevils at 24 h and 48 h were similar and did not differ significantly from each other.

These results indicate that root and outer bark crude extracts caused higher mortalities at the 48 h period, followed by the 24 h time point. All the extracts were less effective at 1 h time point.

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[Data shown on Appendix VI (See Table 24 and 25) stipulate the analysis of variance of mortality by contact toxicity of S. zeamais treated with S. africana crude extracts at three different exposure periods. Appendix VI (See Table 26 and 27) shows the mean post hoc multiple comparisons of mortality by contact toxicity of *S. zeamais* treated with S. africana crude extracts at three different exposure periods.]

4.3.2 Repellent response effects caused by *S. africana* crude extracts against *S. zeamais*

The repellent response of this study was measured as response to weevils crawling away from the source (half filter paper) treated with *S. africana* extracts to the nylon mesh as shown in Plate 7. The results of weevils crawling to the nylon mesh were collected in four observations at three different time interval points.

Repellency for root crude extracts is given in Table 4. The highest response of *S. zeamais* was observed after 1 h period, followed by 30 min and 4 h. Root crude extracts were found to cause up to 100% repellency after 1 hour of exposure.

Table 4. Mean percent repellency for the root crude extracts of against *S. zeamais*

Experiment	[Time (minutes)]		
	30 min	**1h**	**4h**
1	85 ± 5.63 [b]	99.5 ± 0.42 [a]	85 ± 9.57 [b]
2	95 ± 5.0 [a]	100 ± 0.00 [a]	76.7 ± 14.76 [b]
3	86.7 ± 6.14 [b]	100 ± 0.00 [a]	88.3 ± 7.49 [ab]
4	83.33 ± 5.58 [c]	100 ± 0.00 [a]	86.7 ± 8.03 [b]
Overall mean	**87.5 ± 5.59**	**100 ± 0.11**	**84.2 ± 9.96**

Mean (±SE) within a column followed by the same letter are not significantly different (LSD test, P<0.05)

The response ranged closely at each time point. At 30 min post treatment, repellency responses ranged from 83.3% to 95% with a mean of 87.5%. At 1 hour, the range was 99.5 to 100% with a mean of 100%. At 4 h, the range was 76.7% to 88.33% with a mean of 82.4%.

The response of the weevils to the outer bark crude extracts is summarised in Table 5. The crude extracts caused a higher response against the weevils of up to 90% at 1 h and 4 h after treatment, while the lowest repellency was 70% after 4 h.

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The weevil responses ranged from 80% to 8[illegible]% with a mean of 88.3% at 30 min post treatment. At 1 h, the range was 78.33% to 91.67% with a mean of 86%. At 4h, the range was 70% to 91.67% with a mean of 83%.

Table 5. Mean percent repellency for outer bark crude extracts against *S. zeamais*

Experiment	[Time (minutes)]		
	30 min	1h	4h
1	80 ± 8.56 [b]	88.33 ± 4.77 [a]	81.67 ± 7.03 [b]
2	83.33 ± 8.03 [b]	86.67 ± 4.94 [b]	88.33 ± 5.43 [a]
3	88.33 ± 6.01 [a]	91.67 ± 6.54 [a]	70 ± 13.66 [c]
4	88.33 ± 5.43 [a]	78.33 ± 15.15 [c]	91.67 ± 6.54 [a]
Overall mean	**85 ± 7.01**	**86.3 ± 7.85**	**82.9 ± 8.17**

Mean (±SE) within a column followed by the same letter are not significantly different (LSD test, P<0.05)

Figure 10 shows the repellency response of the weevils to *S. africana* crude extracts. Both crude extracts had high repellency rates against adult *S. zeamais*.

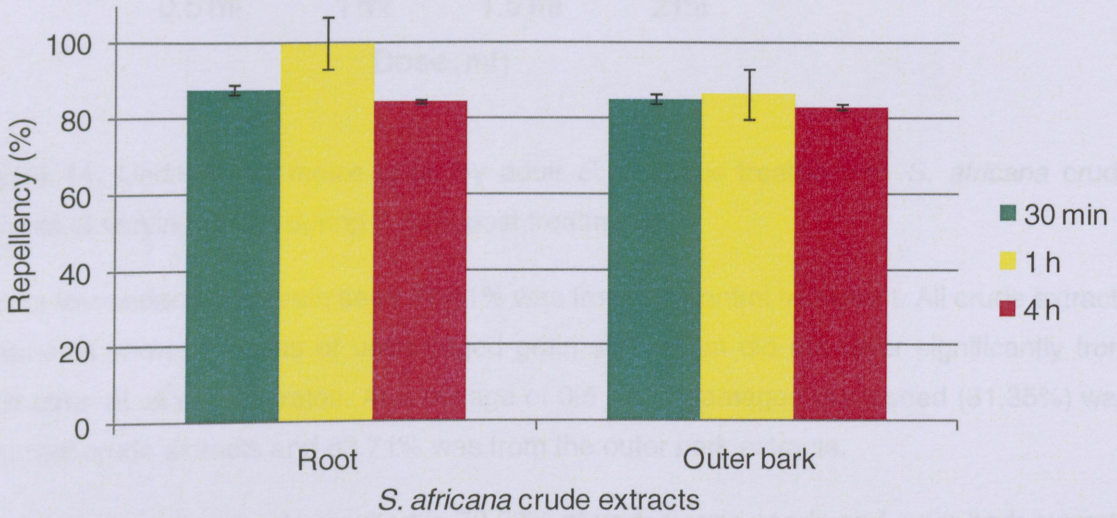


Figure 10. Mean percent repellency response of *S. zeamais* caused by *S. africana* crude extracts

These results show that both crude extracts caused high repellent responses at all time points.

[Appendix VI (See Table 28 and 29) contains the analysis of variance of the repellent response of *S. zeamais* subjected to *S. africana* crude extracts. Data given on Appendix VI (See Table 30 and 31) shows the mean multiple comparisons of the repellent response of *S. zeamais* treated with *S. africana* crude extracts.]

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4.3.3 Feeding deterrence of *S. africana* crude extracts against *S. zeamais*.

The feeding deterrence was determined by visually inspecting the number of damaged and undamaged kernels (seeds) as presented in Plate 11. Plate 12 shows a damaged kernel which is physically and visibly damaged by weevils. Feeding deterrence was measured as percentage of undamaged grain (Figure 11).

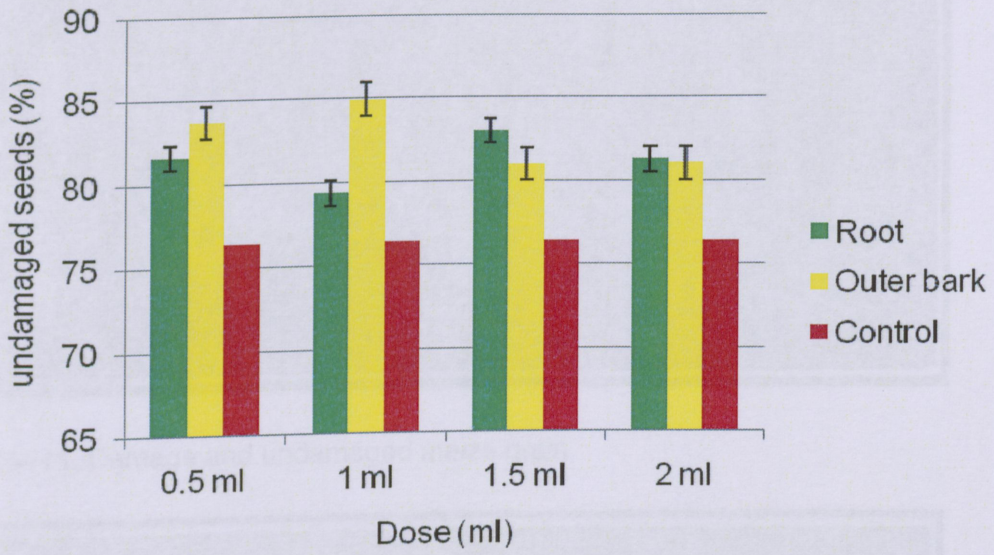


Figure 11. Undamaged maize grain by adult *S. zeamais* treated with *S. africana* crude extracts at varying doses during 7 days post treatment.

The lowest undamaged grain seed 76.41% was from the control treatment. All crude extracts treatments showed results of undamaged grain seeds that did not differ significantly from each other at all dosage rates. At a dosage of 0.5 ml, undamaged grain seed (81.35%) was from root crude extracts and 83.71% was from the outer bark extracts.

At 1 ml, root crude extracts resulted in 79.38% of undamaged seeds and outer bark extracts 84.96% (undamaged seeds). Root crude extracts applied at a dose of 1.5 ml, showed undamaged seeds (82.99%) and outer bark extracts (80.99%). At the highest dose of 2 ml, the highest undamaged seed was 82.52% from root crude extracts and outer bark extracts (81.39%).

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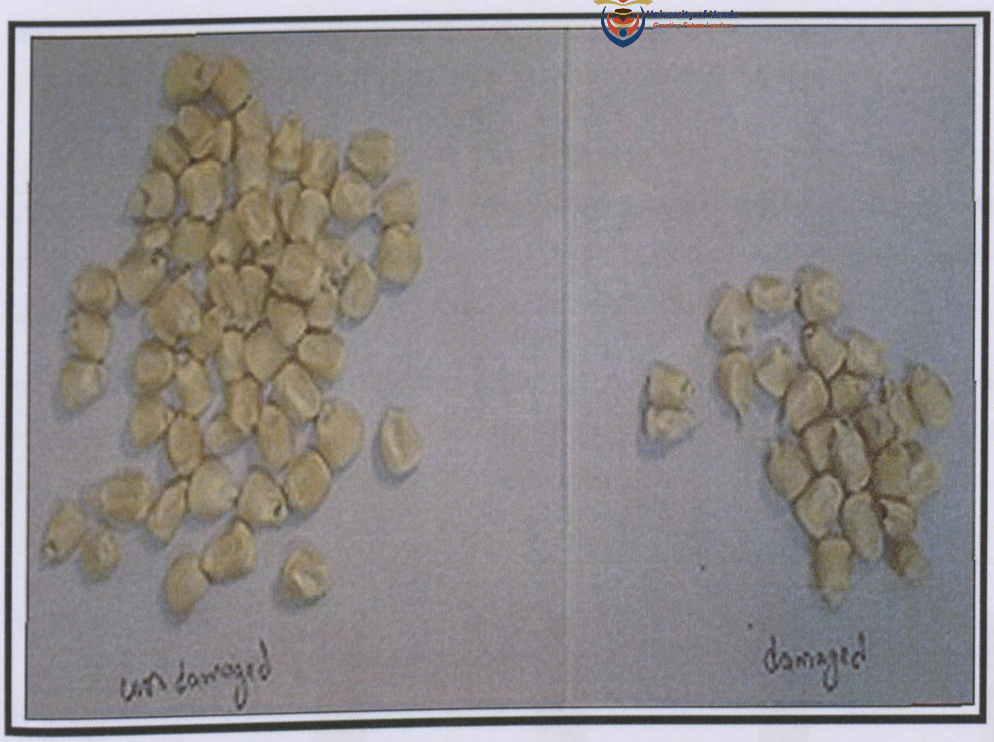


Plate 11. Damage and undamaged maize grain

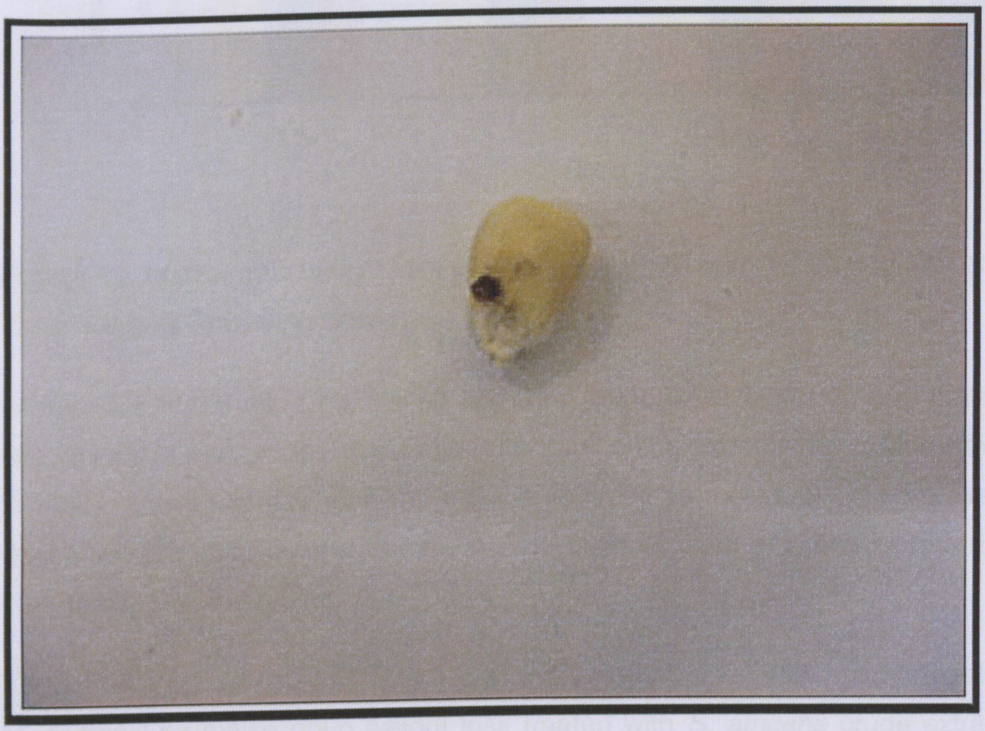


Plate 12. Bored grain by *S. zeamais*

All extracts at all dosages gave good control of the weevils. Undamaged seeds at all dosage rates did not differ from each other and generally deterred the weevils from feeding.

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Results show that all crude extracts resulted in higher percentages of undamaged seeds at all dosage rate. The extracts were effective in controlling the weevils.

[Data given in Appendix VI (See Table 32 and 33) shows the analysis of variance for feeding deterrent by undamaged grain seed treated with *S. africana* crude extracts at different dosages. Appendix VI (Table 34 and 35) presents post hoc multiple comparison of undamaged grain seeds caused by *S. zeamais* at different dosages.]

Weight loss of damaged and undamaged grain seeds caused by *S. zeamais* after 7 days infestation is given in Figure 12. The highest grain weight loss of 17.2% was from the control and this weight loss was significantly the highest.

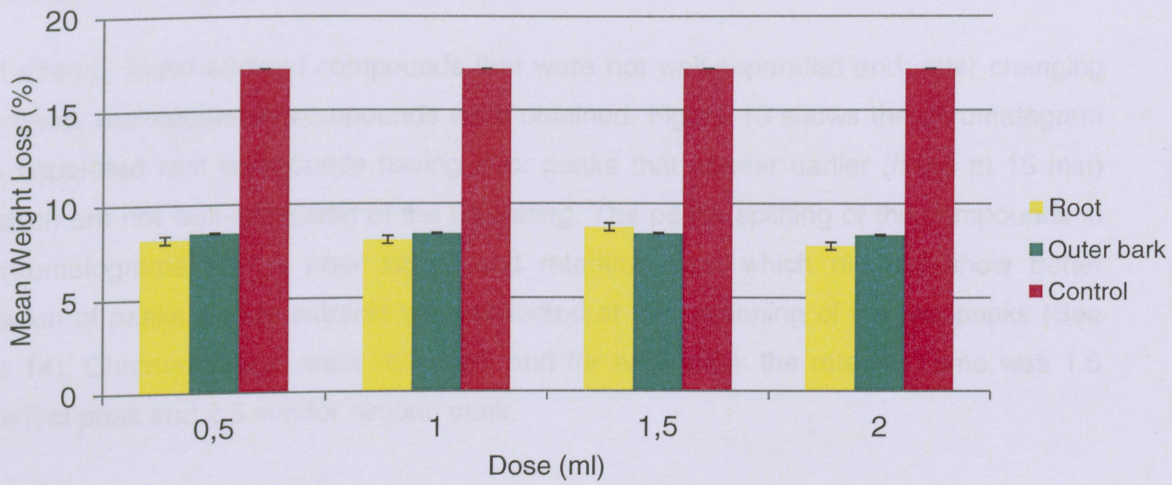


Figure 12. Maize grain weight loss caused by adult *S. zeamais* treated with *S. africana* crude extracts at varying doses.

At dosages of 0.5 ml, 1 ml, 1.5 ml and 2 ml crude extracts per 50 g of maize, maize grain weight loss of root crude extract and outer bark crude extracts did not differ from each other. These results show that root and outer bark crude extracts caused lower weight loss at all doses compared to control treatment. The extracts were effective in deterring the weevils from feeding on the grains.

[Appendix VI (See Table 36 and 37) shows the analysis of variance for feeding deterrent of *S. zeamais* by maize grain weight loss treated with *S. africana* crude extracts at different dosages. Appendix VI (See Table 38 and 39) shows multiple comparison of maize grain weight loss caused by *S. zeamais* at different dosages.]

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5.1 Analysis of crude water extracts by HPLC and GC for the collected pure compounds

Possible compounds of interest of the crude extracts were collected based on the detector peak response. The corresponding good peaks of the individual components were produced by the chromatograph and collected in conical flasks for further spectroscopic analysis. The responses obtained in the study, using HPLC analysis, showed two peaks of interest. The purity of crude extracts compounds of interest were reconfirmed by comparisons of the detected peaks using GC analysis.

5.1.1 Collection of separated compounds from crude water extracts of *S. africana* root

A first attempt result showed compounds that were not well-separated and, after changing the method, well-separated compounds were obtained. Figure 13 shows the chromatogram of the separated root compounds having poor peaks that appear earlier (finish at 15 min) and which are not well-separated at the beginning. The peaks splitting of the compounds in the chromatograms had a poor signal and retention time which did not show better separation of peaks. Crude extracts were collected at the beginning of the two peaks (See Figure 14). Chromatograms were recorded, and for each peak the retention time was 1.5 min for first peak and 2.5 min for second peak.

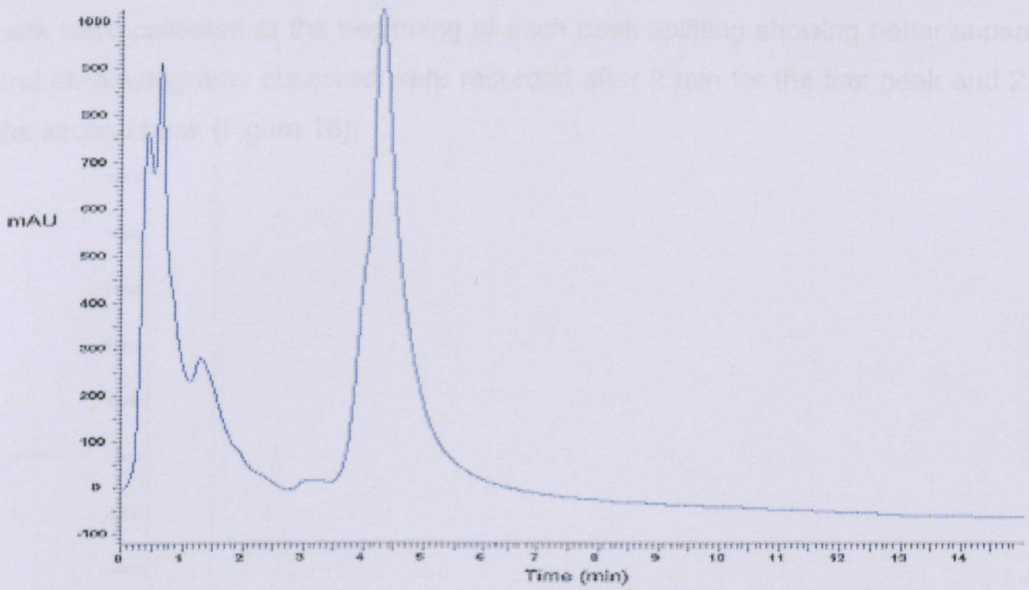


Figure 13. Chromatograms of roots compounds not well separated at the beginning.

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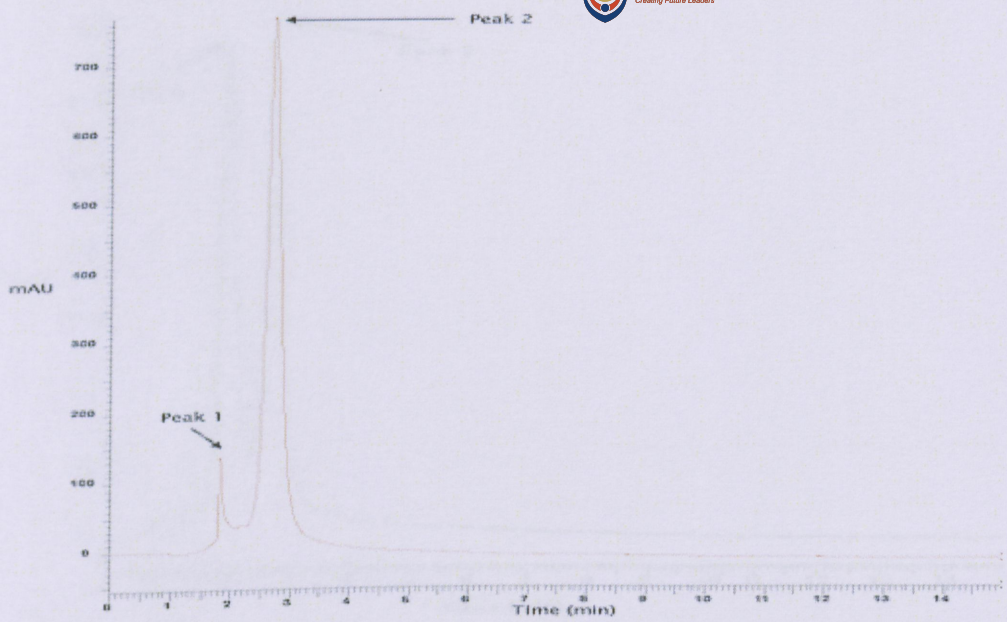


Figure 14. Chromatogram of root compound showing poor separation at the beginning and good separation detected at the end with two different compounds named peak 1 and peak 2 with improved separation.

5.1.2 Collection of separated compounds from crude extracts of *S. africana* outer bark

Similarly, outer bark chromatogram (Figure 15) showed poor peaks that appear early in time (finish at 15 min) and that are not well separated at the beginning. Crude extracts of outer bark were collected at the beginning of each peak splitting showing better separated peaks and chromatograms observed were recorded after 2 min for the first peak and 2.81 min for the second peak (Figure 16).

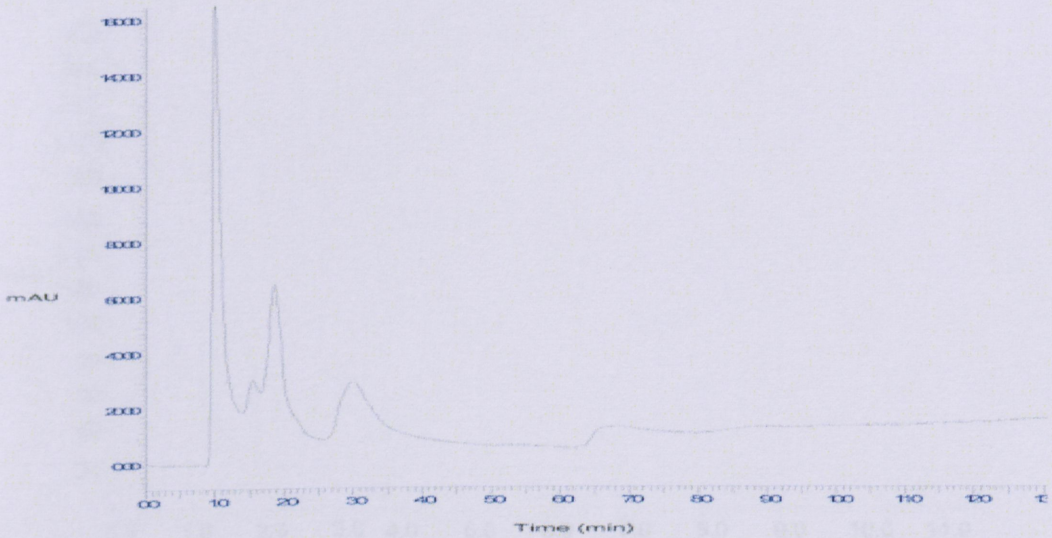


Figure 15. Chromatograms of Outer bark compounds not well separated at the end.

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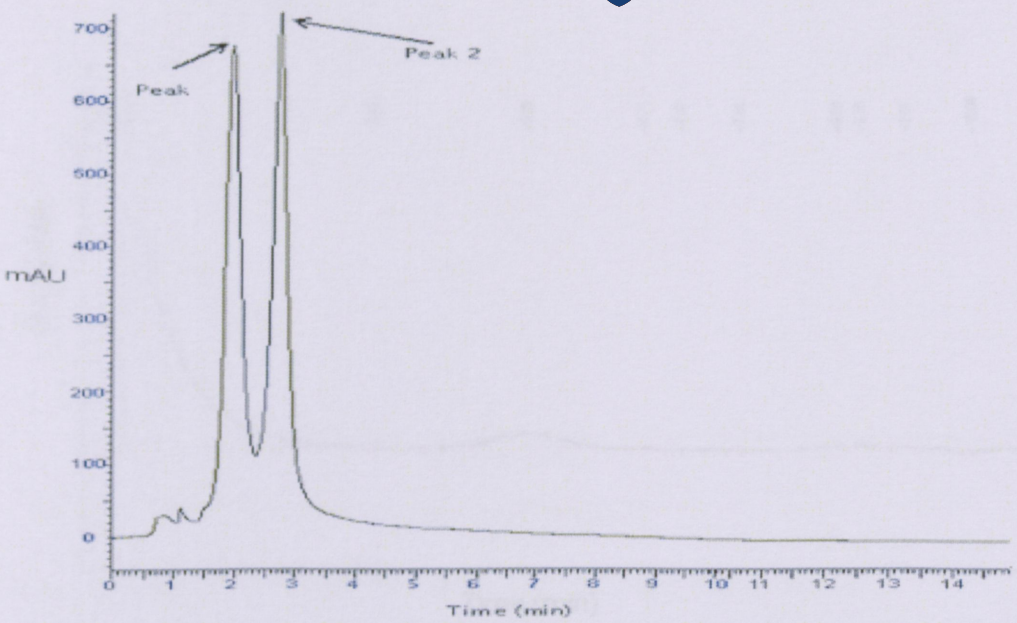


Figure 16. Chromatogram of outer bark compounds showing poor separation at the beginning and good separation detected at the end with two different compounds named peak 1 and peak 2 with improved separation.

5.1.3 Chromatogram documentation of identified compounds of *S. africana* root crude extracts

Gas chromatograms of root crude extracts administered showed a single peak which was assumed to be a major compound (Figure 17). A peak for a compound identified in root crude extracts was identified at 260 °C for 3 min. The single peak found was similar to the two identified peaks observed while using HPLC (Figure 18).

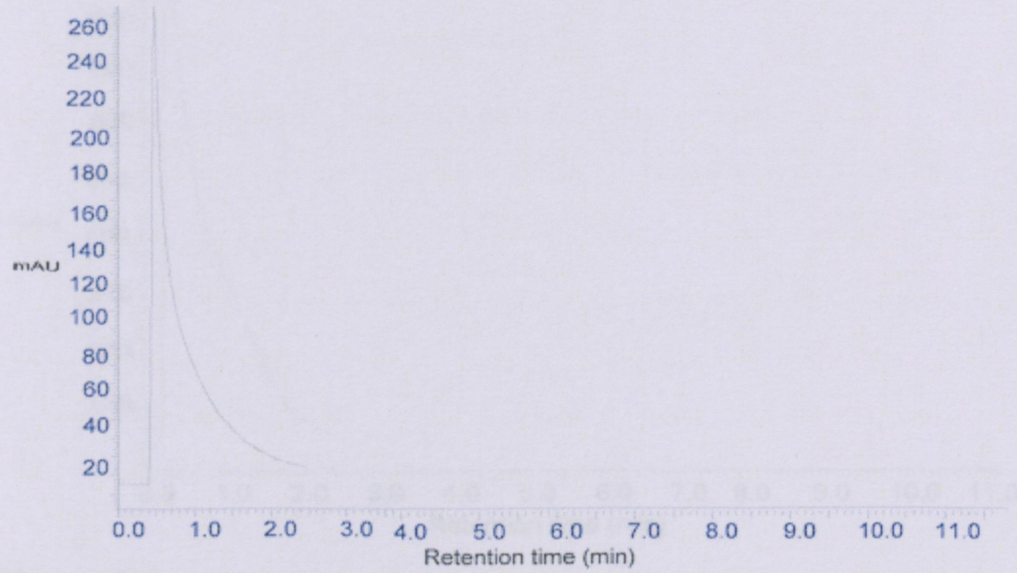


Figure 17. Root crude extracts gas chromatogram

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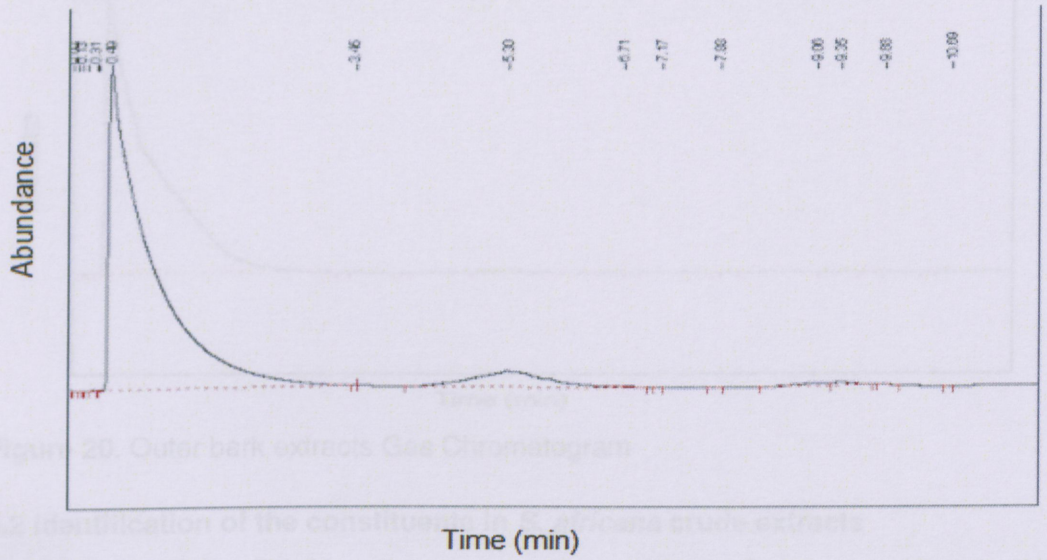


Figure 18. Gas Chromatogram of root extracts

5.1.4 Chromatogram documentation of identified compounds of *S. africana* outer bark crude extracts

Outer bark chromatogram showed a single peak of a compound of interest (Figure 19), which was identified at 900 °C for 3 min. A single peak compound identified in the chromatogram was assumed to be similar to chromatograms of the two peaks found when using HPLC (Figure 20).

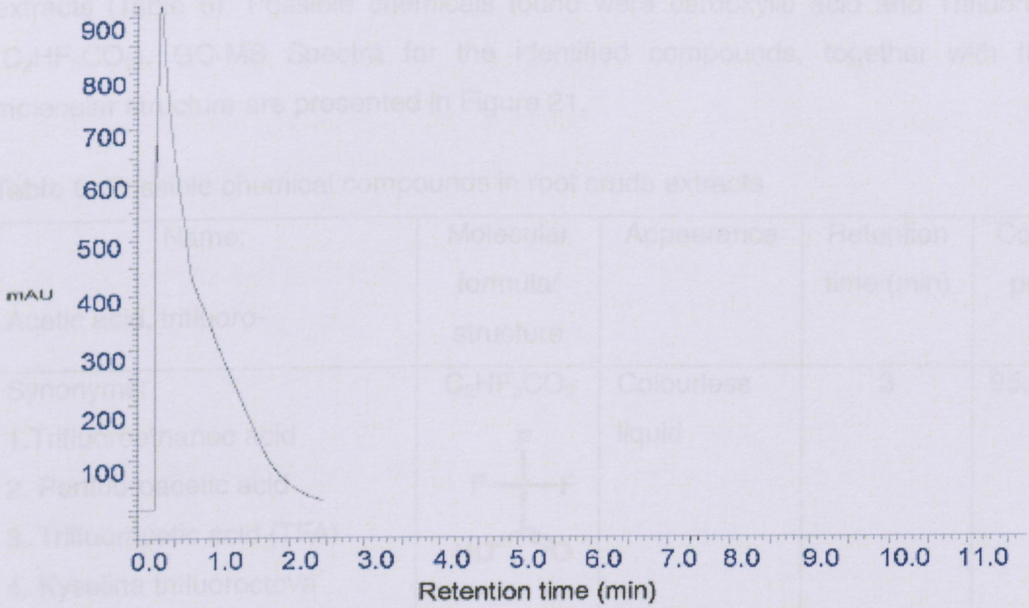


Figure 19. Outer bark crude extracts gas chromatograms

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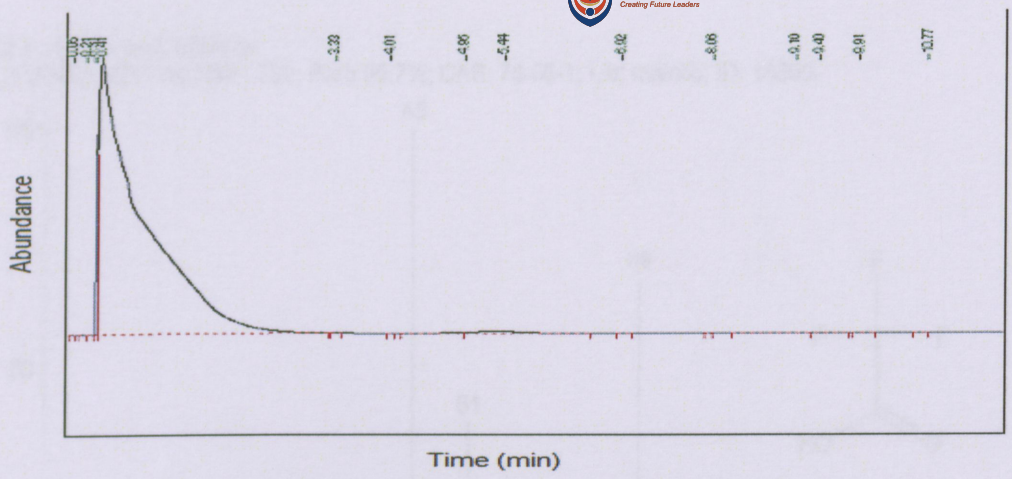


Figure 20. Outer bark extracts Gas Chromatogram

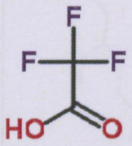
5.2 Identification of the constituents in *S. africana* crude extracts

The analysis of the *S. africana* crude extracts was done after documenting the HPLC and GC/MS chromatograms peaks of each crude extract. The crude extracts chromatograms were used in identifying the compounds by comparing their mass spectra with the library digitalised mass spectra of known compounds (Cannell, 1998; Li *et al.*, 2004). The identification of possible phytochemical compounds was based on the peak area, molecular weight and molecular formula.

5.2.1 Possible chemical composition of *S. africana* root crude extracts

In the HPLC (Figure 14) and GC (Figure 17) chromatograms, only one major compound of interest was identified on each peak. The identified compound comprised of 95.4% of crude extracts (Table 6). Possible chemicals found were carboxylic acid and Trifluoracetic acid ($C_2HF_3CO_2$). GC-MS Spectra for the identified compounds, together with the related molecular structure are presented in Figure 21.

Table 6. Possible chemical compounds in root crude extracts

Name: Acetic acid, trifluoro-	Molecular formula/ structure	Appearance	Retention time (min)	Composition probability (%)
Synonyms: 1.Trifluoroethanoc acid 2. Perfluoroacetic acid 3. Trifluoracetic acid (TFA) 4. Kyselina trifluoroctova 5.UN 2699	$C_2HF_3CO_2$ 	Colourless liquid	3	95.4

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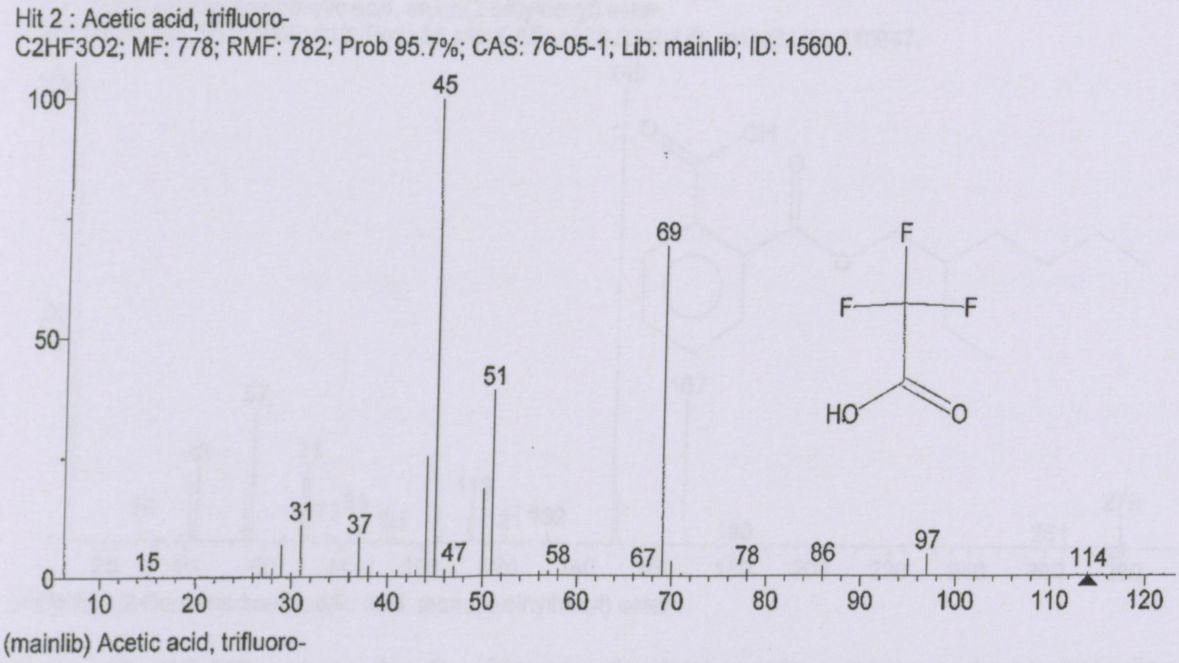
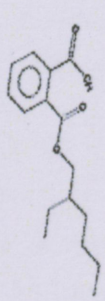


Figure 21. GC-MS spectra for *S. africana* root crude extracts and corresponding molecular structures

5.2.2 Possible chemical crude extracts of *S. africana* outer bark crude extracts

The chemical constituents of outer bark on HPLC (Figure 16) and GC (Figure 19) chromatograms identified one major compound representing 35.4% (Table 7). Identified chemical compound is of aromatic carboxylic acid (1,2-Benzenedicarboxylic acid). The GC-MS spectrum for the identified possible compound is presented in Figure 22.

Table 7. Possible chemical compounds in outer bark crude extracts

Name: 1,2-Benzenedicarboxylic acid, mono (2-ethylhexyl) ester	Molecular formula/ structure	Appearance	Retention time (min)	Composition probability (%)
1. Mehp 2. Mono (2-ethylhexyl) phthalate 3. Monoethylhexyl phthalate 4. Phthalic acid, mono-2-ethylhexyl ester 5. 2-([(2-Ethylhexyl)oxy] carbonyl) benzoic acid	$C_{16}H_{22}O_4$ 	Colourless liquid	3	35.4

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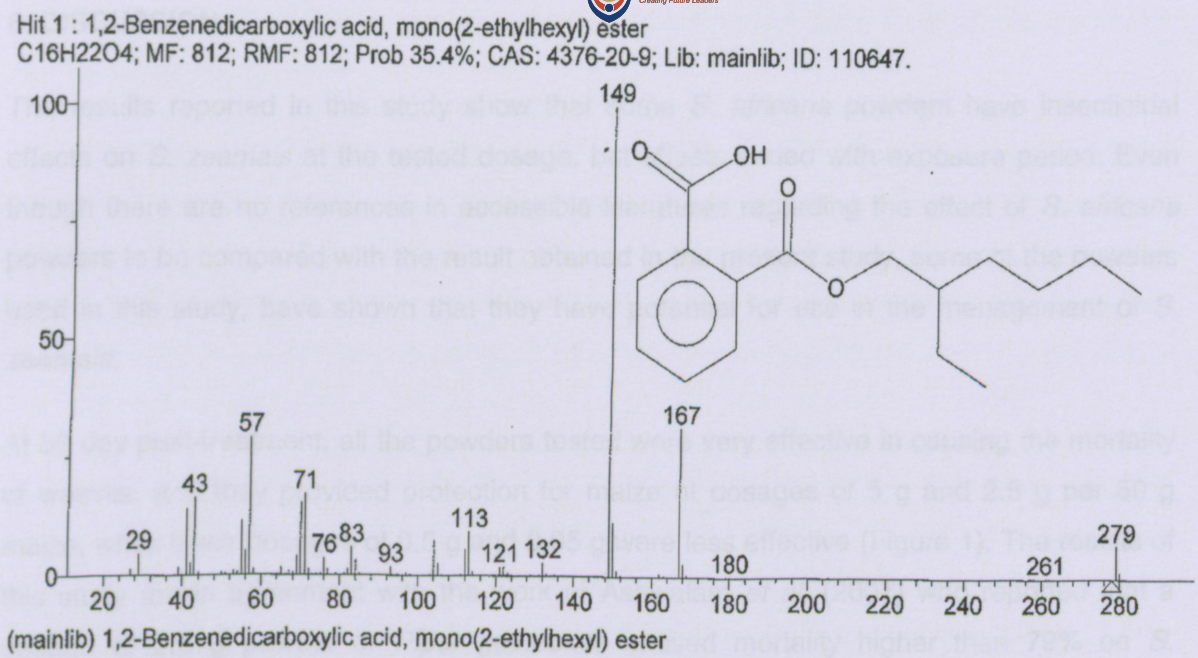


Figure 22. GC-MS spectra for *S. africana* outer bark crude extracts and corresponding molecular structures

These results indicate that chemical analysis of *S. africana* crude extracts showed only one major compound of interest identified in each extract. The root crude extracts component representing 95.4% of the identified compound, the trifluoracetic acid and for the outer bark crude extracts (35.4%) 1,2-benzenedicarboxylic acid was identified.

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6. DISCUSSION

The results reported in this study show that some *S. africana* powders have insecticidal effects on *S. zeamais* at the tested dosage, but effects varied with exposure period. Even though there are no references in accessible literatures regarding the effect of *S. africana* powders to be compared with the result obtained in the present study, some of the powders used in this study, have shown that they have potential for use in the management of *S. zeamais*.

At 30 day post-treatment, all the powders tested were very effective in causing the mortality of weevils, and they provided protection for maize at dosages of 5 g and 2.5 g per 50 g maize, while lower dosages of 0.5 g and 0.05 g were less effective (Figure 1). The results of this study are in agreement with the work of Asawalam *et al.* (2007) who reported that a dosage of 2.0 g powder of *Piper guineense* caused mortality higher than 79% on *S. zeamais.*

The findings of this study are similar to observations of Islam (2012) who reported that powders of *Capsicum annum and Capsicum frutescence* at the dosage of 2 g, 4g and 6 g per 50 g maize grain caused significant mortalities to *S. zeamais*. Udo (2011) also found that at 5 g dosage, the powders of *Zanthoxylum xanthoxyloides* root and bark caused 100% mortality and significantly inhibited development of *S. zeamais* when compared with the control treatment. Asawalam and Chukwuekezie (2012) stated that plant powders of *Gnetum africanum* and *Curcuma longa* increased adult mortality and suppressed adult emergence after 35 days post-treatment.

In this study the highest weight loss of maize was observed when maize was treated with outer bark powder, followed by seed, leaf and root powders. The least weight loss was observed on inner bark powders. Inner bark powders showed no weight loss and provided protection at a dosage of 0.5 g/ 50 g and 2.5 g/ 50 g of maize grain (Figure 4). This finding is in line with Mulungu *et al.* (2007) who observed that *Carica papaya*, *Azadirachta indica* and *Lantana camara* powders reduce grain damage and weight loss of maize grain.

The results of inner bark powders treatment during the 30 day post-treatment showed lower grain weight loss compared to the outer bark, leaf, seed and root powder treatments. This indicates that inner bark powders were effective in controlling the weevils from feeding on the grains unlike the other powders. At 30 days post treatment, inner bark powders provided the best protection, showing that they have insecticidal properties. However, they were not selected for bioassays and chemical analysis. For plant powders, selection criteria was

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based upon powders effectively killing the weevils and at 90d outer bark and root powders had least grain weight loss.

The emergence of adult weevils from the maize treated with *S. africana* powders at different dosages shows that outer bark powders and the root caused a lower adult emergence (Figure 7-8). This result shows that outer bark and root powders have insecticidal effects in reducing adult emergence compared to other powders. Reduction in the number of adults could have been caused by the powders affecting the development of weevils into adults and also their feeding.

This study has shown that toxicity of *S. africana* powders increased with an increase in dosage, as well as the period of exposure of plant powders. The best protection was observed on root powders treatment because it resulted in complete mortality at the highest dosage level (5 g/ 50 g), while other powders did not cause complete mortality, but they were higher at the highest dosage (5 g/ 50 g) after 90 days of treatment (Figure 3).

At 60 and 90 days periods, all powders showed high maize grain weight loss that can be attributed to low weevil mortality and high weevil emergence, which resulted in high grain weight loss. This could be because, under prolonged exposure the effectiveness of all powders against the weevil might have decreased leading to low mortality and high weevil emergence, resulting in high grain weight loss. Muzemu *et al.* (2013) stated that *Eucalyptus tereticornis* powders caused high weevil mortality and less grain weight loss.

Laboratory bioassay results showed that *S. africana* crude extracts have insecticidal toxicity against *S. zeamais*. Root crude extracts and outer bark caused weevil mortality after 48h treatment and their toxicity increased with increase in exposure time (Figure 9). This study showed that *S. africana* crude extracts which were tested possess contact insecticidal activity against *S. zeamais*. This observation is in agreement with Wekesa *et al.* (2011) who argued that contact toxicity assay gave more than 50% mortality to *Sitophilus zeamais* at 48 h exposure to *Hyptis spicigera* extracts.

Repellency bioassays showed that *S. africana* crude extracts were effective in repelling the weevils and providing protection at all exposure periods (Figure 10). The crude extracts were observed to be more effective after 1 h exposure period, giving a higher repellent response of more than 85% against the weevil.

The repellent responses confirms the study made by Toloza *et al.* (2006) who stated that essential oil extracts of *Mentha pulegium* L have benzyl alcohol components, which can cause up to 70% repellency. Morgan (2009) also observed that *Azadirachta indica* extracts

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caused up to 90% repellency due to azadirachtine active compounds. This shows that *S. africana* extracts have compounds that repel weevils with carboxylic acids components such as trifluoracetic acid compounds (roots extracts) and 1,2-benzenedicarboxylic acid (outer bark extracts) compounds. This is also in agreement with Isigi (2013) who argued that *L. javanica* essential oil extracts containing many compounds, such as alcohols, ester, nitrogen containing, ketones, sesquiterpene and hydrated monoterpene, can repel *S. zeamais*.

Feeding deterrence bioassays showed that the highest maize weight loss was observed in control treatment than in *S. africana* crude extracts treatments at all dosage rates. *S. africana* crude extracts were observed to deter the weevils from feeding when there was an increase in dosage (Figure 11-12). The results of the feeding deterrent test are similar to the findings made by Babarinde *et al.* (2008) who said that *Xylopia aethiopica* seed extracts reduce maize grain weight loss to less than 7% at a higher dosage of 0.8 ml per 20 g of maize grain.

Mukanga *et al.* (2010) showed that anti-feeding activity of plant extracts increases with an increase in dosage. The feeding deterrence effect results of the *S. africana* crude extracts showed that at all dosages there was lower damage to seeds and a higher number of undamaged seeds, proving that the extracts were effective in deterring the weevils from feeding.

Bioassay results showed that *S. africana* crude extracts recorded high repellent responses (more than 80%) against the weevils and lower contact toxicity (up to 35%) and feeding deterrent (more than 75%). It could be argued that the *S. africana* extracts gave protection against the weevils mainly as a repellent. This is in agreement with a claim made by local farmers in Vhembe (Musanda Mavhunga, pers. comm.), who claimed that weevils are repelled by fresh outer bark extracts. This study shows the potential of *S. africana* root and outer bark extracts as grain protectants (repellent) against *S. zeamais.* Olivero-Verbel and Stashenko (2010) showed similar results by evaluating the plant extracts of *Cymbopogon citratus* and *Eucalyptus citriodora* essential oil extracts having components that cause high repellent activity and lower toxicity against *T. castaneum*. Furthermore, Obeng-Ofori *et al.* (1997) observed that pure compounds of *Ocimum kenyense* (1, 8 cineole) have repellent and toxicant activities against *S. zeamais*.

This study showed that *S. africana* crude extracts have the potential to be used as grain protectants against maize weevils by acting as repellents, particularly at 30d after infestation (Figure 1).

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The major possible component in root crude extracts representing 95.4% of the identified compound, was trifluoracetic acid, while that of outer bark crude extract, representing 35.4% of the compound, was 1,2-benzenedicarboxylic acid. This finding indicates that *S. africana* root and outer bark extracts have one major chemical component each which has insecticidal toxicity effects against the weevils.

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7. CONCLUDING REMARKS AND RECOMMENDATION

The objective of the research study was to assess the insecticidal activity of *Spirostachys africana* extracts on *S. zeamais*. The findings of the study support the hypothesis that extracts from different parts of *S. africana* affect the development of and cause mortality in *S. zeamais*. The identified insecticidal components were effective in causing mortality, reducing adult emergence and reduced the feeding of weevils on maize grain.

S. africana powders and crude extracts can be used by local farmers to repel the weevils from infesting the grain. Root and outer bark extracts can be recommended for use as they cause mortality and repel weevils more than the other plant extracts. Root and outer bark extracts can offer great potential as storage grain protectants that can be easily adopted by farmers for long and short term storage, provided there is continuous treatment and sampling of grain. The findings of this study indicate that botanical extracts from *S. africana* have different insecticidal activities against *S. zeamais* and that these can be utilised as alternatives of synthetic insecticides. There is merit, in future, of assessing the effect of *S. africana* inner bark extracts which caused *S. zeamais* not to feed on maize grain at 30 days post-treatment. *S. africana* root and outer bark powders also need further bioassay investigation to confirm their efficacy.

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Appendix I: Results for toxicity effect of plant powder against *S. zeamais* at 30 days post treatment

Table 8. Analysis of variance for percent mortality of *S. zeamais* caused by *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E) powders.

Anova for leaves powder (A) treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	5154.702	4	1288.676	1.659*
Error	12426.25	16	776.641	
Total	17580.95	20		

Anova for seed powder (B) treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	4021.1	4	1005.3	2.57*
Error	6257.5	16	391.09	
Total	10279	20		

Anova for root powder (C) treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	24185.06	4	6046.265	30.338**
Error	3188.75	16	199.297	
Total	27373.81	20		

Anova for outer bark powder (D) treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	10337.738	4	2584.435	4.978*
Error	8307.5	16	519.219	
Total	18645.238	20		

Anova for inner bark powder (E) treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	134.167	4	33.542	0.645^{NS}
Error	832.5	16	52.031	
Total	966.667	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 9. LSD post hoc multiple comparisons of mortality of *S. zeamais caused* by *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 30 days post treatment.

Leave powder (A) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-19.75	18.69461	0.306	-59.3808	19.8808
	2.5	-46.000*	18.69461	0.026	-85.6308	-6.3692
	0.5	-24.75	18.69461	0.204	-64.3808	14.8808
	0.05	-32.25	18.69461	0.104	-71.8808	7.3808
0.05	5	12.5	19.70584	0.535	-29.2745	54.2745
	2.5	-13.75	19.70584	0.495	-55.5245	28.0245
	0.5	7.5	19.70584	0.709	-34.2745	49.2745
	0	32.25	18.69461	0.104	-7.3808	71.8808
0.5	5	5	19.70584	0.803	-36.7745	46.7745
	2.5	-21.25	19.70584	0.297	-63.0245	20.5245
	0.05	-7.5	19.70584	0.709	-49.2745	34.2745
	0	24.75	18.69461	0.204	-14.8808	64.3808
2.5	5	26.25	19.70584	0.201	-15.5245	68.0245
	0.5	21.25	19.70584	0.297	-20.5245	63.0245
	0.05	13.75	19.70584	0.495	-28.0245	55.5245
	0	46.000*	18.69461	0.026	6.3692	85.6308
5	2.5	-26.25	19.70584	0.201	-68.0245	15.5245
	0.5	-5	19.70584	0.803	-46.7745	36.7745
	0.05	-12.5	19.70584	0.535	-54.2745	29.2745
	0	19.75	18.69461	0.306	-19.8808	59.3808

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-27.25	13.266	0.057	-55.3731	0.8731
	2.5	-38.50000*	13.266	0.01	-66.6231	-10.3769

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	0.5	-23.5	13.266	0.096	-51.6231	4.6231
	0.05	-9.75	13.266	0.473	-37.8731	18.3731
0.05	5	-17.5	13.983	0.229	-47.1443	12.1443
	2.5	-28.75	13.983	0.056	-58.3943	0.8943
	0.5	-13.75	13.983	0.34	-43.3943	15.8943
	0	9.75	13.266	0.473	-18.3731	37.8731
0.5	5	-3.75	13.983	0.792	-33.3943	25.8943
	2.5	-15	13.983	0.299	-44.6443	14.6443
	0.05	13.75	13.983	0.34	-15.8943	43.3943
	0	23.5	13.266	0.096	-4.6231	51.6231
2.5	5	11.25	13.983	0.433	-18.3943	40.8943
	0.5	15	13.983	0.299	-14.6443	44.6443
	0.05	28.75	13.983	0.056	-0.8943	58.3943
	0	38.50000*	13.266	0.01	10.3769	66.6231
5	2.5	-11.25	13.983	0.433	-40.8943	18.3943
	0.5	3.75	13.983	0.792	-25.8943	33.3943
	0.05	17.5	13.983	0.229	-12.1443	47.1443
	0	27.25	13.266	0.057	-0.8731	55.3731

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-88.5000*	9.470	0	-108.5758	-68.4242
	2.5	-88.5000*	9.470	0	-108.5758	-68.4242
	0.5	-56.0000*	9.470	0	-76.0758	-35.9242
	0.05	-59.7500*	9.470	0	-79.8258	-39.6742
0.05	5	-28.7500*	9.982	0.011	-49.9118	-7.5882
	2.5	-28.7500*	9.982	0.011	-49.9118	-7.5882
	0.5	3.75	9.982	0.712	-17.4118	24.9118
	0	59.7500*	9.470	0	39.6742	79.8258
0.5	5	-32.5000*	9.982	0.005	-53.6618	-11.3382
	2.5	-32.5000*	9.982	0.005	-53.6618	-11.3382

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	0.05	-3.75	9.982	0.712	-24.9118	17.4118
	0	56.0000*	9.470	0	35.9242	76.0758
2.5	5	0	9.982	1	-21.1618	21.1618
	0.5	32.5000*	9.982	0.005	11.3382	53.6618
	0.05	28.7500*	9.982	0.011	7.5882	49.9118
	0	88.5000*	9.470	0	68.4242	108.5758
5	2.5	0	9.982	1	-21.1618	21.1618
	0.5	32.5000*	9.982	0.005	11.3382	53.6618
	0.05	28.7500*	9.982	0.011	7.5882	49.9118
	0	88.5000*	9.470	0	68.4242	108.5758

*The mean difference is significant at the .05 level.

Outer bark (D) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-67.25000*	15.28556	0	-99.6539	-34.846
	2.5	-38.50000*	15.28556	0.023	-70.9039	-6.0961
	0.5	-34.75000*	15.28556	0.037	-67.1539	-2.3461
	0.05	-28.5	15.28556	0.081	-60.9039	3.9039
0.05	5	-38.75000*	16.1124	0.029	-72.9068	-4.5932
	2.5	-10	16.1124	0.544	-44.1568	24.1568
	0.5	-6.25	16.1124	0.703	-40.4068	27.9068
	0	28.5	15.28556	0.081	-3.9039	60.9039
0.5	5	-32.5	16.1124	0.061	-66.6568	1.6568
	2.5	-3.75	16.1124	0.819	-37.9068	30.4068
	0.05	6.25	16.1124	0.703	-27.9068	40.4068
	0	34.75000*	15.28556	0.037	2.3461	67.1539
2.5	5	-28.75	16.1124	0.093	-62.9068	5.4068
	0.5	3.75	16.1124	0.819	-30.4068	37.9068
	0.05	10	16.1124	0.544	-24.1568	44.1568
	0	38.50000*	15.28556	0.023	6.0961	70.9039
5	2.5	28.75	16.1124	0.093	-5.4068	62.9068
	0.5	32.5	16.1124	0.061	-1.6568	66.6568
	0.05	38.75000*	16.1124	0.029	4.5932	72.9068
	0	67.25000*	15.28556	0	34.8461	99.6539

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*The mean difference is significant at the .05 level.

Inner bark (E) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-7.25	4.83881	0.154	-17.5078	3.0078
	2.5	-3.5	4.83881	0.48	-13.7578	6.7578
	0.5	-1	4.83881	0.839	-11.2578	9.2578
	0.05	-2.25	4.83881	0.648	-12.5078	8.0078
0.05	5	-5	5.10055	0.342	-15.8127	5.8127
	2.5	-1.25	5.10055	0.81	-12.0627	9.5627
	0.5	1.25	5.10055	0.81	-9.5627	12.0627
	0	2.25	4.83881	0.648	-8.0078	12.5078
0.5	5	-6.25	5.10055	0.238	-17.0627	4.5627
	2.5	-2.5	5.10055	0.631	-13.3127	8.3127
	0.05	-1.25	5.10055	0.81	-12.0627	9.5627
	0	1	4.83881	0.839	-9.2578	11.2578
2.5	5	-3.75	5.10055	0.473	-14.5627	7.0627
	0.5	2.5	5.10055	0.631	-8.3127	13.3127
	0.05	1.25	5.10055	0.81	-9.5627	12.0627
	0	3.5	4.83881	0.48	-6.7578	13.7578
5	2.5	3.75	5.10055	0.473	-7.0627	14.5627
	0.5	6.25	5.10055	0.238	-4.5627	17.0627
	0.05	5	5.10055	0.342	-5.8127	15.8127
	0	7.25	4.83881	0.154	-3.0078	17.5078

*The mean difference is significant at the .05 level.

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Appendix II: Result of mortality caused by *S. africana* powders at 60 and 90 days post treatment

Table 10. Analysis of variance of mortality of *S. zeamais* caused by *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E) powders at 60 day post treatment.

Anova for leave (A) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	1816.135	4	454.034	0.84^{NS}
Error	8649.018	16	540.564	
Total	10465.152	20		

Anova for inner bark (E) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	2223.779	4	555.945	2.872*
Error	3097.048	16	193.565	
Total	5320.827	20		

Anova for root (C) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	1334.737	4	333.684	0.432^{NS}
Error	12353.675	16	772.105	
Total	13688.412	20		

Anova for outer bark (D) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	1008.107	4	252.027	0.428^{NS}
Error	9431.425	16	589.464	
Total	10439.532	20		

Anova for seed (B) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	1250.051	4	312.513	0.51*
Error	9795.708	16	612.232	
Total	11045.758	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 11. Analysis of variance of mortality of *S. zeamais* caused by *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E) powders at 90 day post treatment.

Anova for leave (A) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	2606.873	4	651.718	1.558*
Error	6692.862	16	418.304	
Total	9299.735	20		

Anova for inner bark (E) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	3655.621	4	913.905	1.935*
Error	7557.498	16	472.344	
Total	11213.118	20		

Anova for root (C) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	2971.968	4	742.992	6.061*
Error	1961.4	16	122.587	
Total	4933.367	20		

Anova for outer bark (D) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	3270.877	4	817.719	7.793*
Error	1678.929	16	104.933	
Total	4949.806	20		

Anova for seed (B) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	2619.03	4	654.757	4.28*
Error	2447.618	16	152.976	
Total	5066.648	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 12. LSD post hoc multiple comparisons of mortality of *S. zeamais caused* by *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 60 days post treatment.

Leave powder (A) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-25	15.6	0.129	-58.063	8.0633
	2.5	-12.325	15.6	0.441	-45.388	20.7383
	0.5	-18.2	15.6	0.26	-51.263	14.8633
	0.05	-22.45	15.6	0.169	-55.513	10.6133
0.05	5	-2.55	16.4	0.879	-37.402	32.3018
	2.5	10.125	16.4	0.547	-24.727	44.9768
	0.5	4.25	16.4	0.799	-30.602	39.1018
	0	22.45	15.6	0.169	-10.613	55.5133
0.5	5	-6.8	16.4	0.685	-41.652	28.0518
	2.5	5.875	16.4	0.725	-28.977	40.7268
	0.05	-4.25	16.4	0.799	-39.102	30.6018
	0	18.2	15.6	0.26	-14.863	51.2633
2.5	5	-12.675	16.4	0.452	-47.527	22.1768
	0.5	-5.875	16.4	0.725	-40.727	28.9768
	0.05	-10.125	16.4	0.547	-44.977	24.7268
	0	12.325	15.6	0.441	-20.738	45.3883
5	2.5	12.675	16.4	0.452	-22.177	47.5268
	0.5	6.8	16.4	0.685	-28.052	41.6518
	0.05	2.55	16.4	0.879	-32.302	37.4018
	0	25	15.6	0.129	-8.0633	58.0633

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-13.325	14.6	0.374	-44.232	17.5816
	2.5	-21.5	14.6	0.16	-52.407	9.4066
	0.5	-33.95000*	14.6	0.033	-64.857	-3.0434

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	0.05	-33.20000*	14.6	0.037	-64.107	-2.2934
0.05	5	19.875	15.4	0.214	-12.704	52.4535
	2.5	11.7	15.4	0.458	-20.879	44.2785
	0.5	-0.75	15.4	0.962	-33.329	31.8285
	0	33.20000*	14.6	0.037	2.2934	64.1066
0.5	5	20.625	15.4	0.198	-11.954	53.2035
	2.5	12.45	15.4	0.43	-20.129	45.0285
	0.05	0.75	15.4	0.962	-31.829	33.3285
	0	33.95000*	14.6	0.033	3.0434	64.8566
2.5	5	8.175	15.4	0.602	-24.404	40.7535
	0.5	-12.45	15.4	0.43	-45.029	20.1285
	0.05	-11.7	15.4	0.458	-44.279	20.8785
	0	21.5	14.6	0.16	-9.4066	52.4066
5	2.5	-8.175	15.4	0.602	-40.754	24.4035
	0.5	-20.625	15.4	0.198	-53.204	11.9535
	0.05	-19.875	15.4	0.214	-52.454	12.7035
	0	13.325	14.6	0.374	-17.582	44.2316

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

(I) Dose	(J) Dose	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-6.525	18.6	0.731	-46.04	32.9899
	2.5	-15.5	18.6	0.418	-55.015	24.0149
	0.5	-22.5	18.6	0.245	-62.015	17.0149
	0.05	-14.175	18.6	0.458	-53.69	25.3399
0.05	5	7.65	19.6	0.702	-34.002	49.3024
	2.5	-1.325	19.6	0.947	-42.977	40.3274
	0.5	-8.325	19.6	0.677	-49.977	33.3274
	0	14.175	18.6	0.458	-25.34	53.6899
0.5	5	15.975	19.6	0.428	-25.677	57.6274
	2.5	7	19.6	0.726	-34.652	48.6524
	0.05	8.325	19.6	0.677	-33.327	49.9774
	0	22.5	18.6	0.245	-17.015	62.0149
2.5	5	8.975	19.6	0.654	-32.677	50.6274

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	0.5	-7	19.6	0.726	-48.652	34.6524
	0.05	1.325	19.6	0.947	-40.327	42.9774
	0	15.5	18.6	0.418	-24.015	55.0149
5	2.5	-8.975	19.6	0.654	-50.627	32.6774
	0.5	-15.975	19.6	0.428	-57.627	25.6774
	0.05	-7.65	19.6	0.702	-49.302	34.0024
	0	6.525	18.6	0.731	-32.99	46.0399

*The mean difference is significant at the .05 level.

Outer bark (D) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-15.4	16.3	0.358	-49.926	19.1264
	2.5	-16.925	16.3	0.314	-51.451	17.6014
	0.5	-15.75	16.3	0.348	-50.276	18.7764
	0.05	-16.775	16.3	0.318	-51.301	17.7514
0.05	5	1.375	17.2	0.937	-35.019	37.769
	2.5	-0.15	17.2	0.993	-36.544	36.244
	0.5	1.025	17.2	0.953	-35.369	37.419
	0	16.775	16.3	0.318	-17.751	51.3014
0.5	5	0.35	17.2	0.984	-36.044	36.744
	2.5	-1.175	17.2	0.946	-37.569	35.219
	0.05	-1.025	17.2	0.953	-37.419	35.369
	0	15.75	16.3	0.348	-18.776	50.2764
2.5	5	1.525	17.2	0.93	-34.869	37.919
	0.5	1.175	17.2	0.946	-35.219	37.569
	0.05	0.15	17.2	0.993	-36.244	36.544
	0	16.925	16.3	0.314	-17.601	51.4514
5	2.5	-1.525	17.2	0.93	-37.919	34.869
	0.5	-0.35	17.2	0.984	-36.744	36.044
	0.05	-1.375	17.2	0.937	-37.769	35.019
	0	15.4	16.3	0.358	-19.126	49.9264

*The mean difference is significant at the .05 level.

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Inner bark (E) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-17.525	16.6	0.307	-52.712	17.6619
	2.5	-14.7	16.6	0.389	-49.887	20.4869
	0.5	-15	16.6	0.38	-50.187	20.1869
	0.05	-21.6	16.6	0.212	-56.787	13.5869
0.05	5	4.075	17.5	0.819	-33.015	41.1652
	2.5	6.9	17.5	0.699	-30.19	43.9902
	0.5	6.6	17.5	0.711	-30.49	43.6902
	0	21.6	16.6	0.212	-13.587	56.7869
0.5	5	-2.525	17.5	0.887	-39.615	34.5652
	2.5	0.3	17.5	0.987	-36.79	37.3902
	0.05	-6.6	17.5	0.711	-43.69	30.4902
	0	15	16.6	0.38	-20.187	50.1869
2.5	5	-2.825	17.5	0.874	-39.915	34.2652
	0.5	-0.3	17.5	0.987	-37.39	36.7902
	0.05	-6.9	17.5	0.699	-43.99	30.1902
	0	14.7	16.6	0.389	-20.487	49.8869
5	2.5	2.825	17.5	0.874	-34.265	39.9152
	0.5	2.525	17.5	0.887	-34.565	39.6152
	0.05	-4.075	17.5	0.819	-41.165	33.0152
	0	17.525	16.6	0.307	-17.662	52.7119

*The mean difference is significant at the .05 level.

Table 13. LSD post hoc multiple comparisons of mortality of *S. zeamais caused* by *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 90 days post treatment.

Leave powder (A) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-28.228	13.72	0.056	-57.313	0.857
	2.5	-24.433	13.72	0.094	-53.518	4.652
	0.5	-22.7155	13.72	0.117	-51.8005	6.3695

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	0.05	-7.8705	13.72	0.574	-36.9555	21.2145
0.05	5	-20.3575	14.462	0.178	-51.0158	10.3008
	2.5	-16.5625	14.462	0.269	-47.2208	14.0958
	0.5	-14.845	14.462	0.32	-45.5033	15.8133
	0	7.8705	13.72	0.574	-21.2145	36.9555
0.5	5	-5.5125	14.462	0.708	-36.1708	25.1458
	2.5	-1.7175	14.462	0.907	-32.3758	28.9408
	0.05	14.845	14.462	0.32	-15.8133	45.5033
	0	22.7155	13.72	0.117	-6.3695	51.8005
2.5	5	-3.795	14.462	0.796	-34.4533	26.8633
	0.5	1.7175	14.462	0.907	-28.9408	32.3758
	0.05	16.5625	14.462	0.269	-14.0958	47.2208
	0	24.433	13.72	0.094	-4.652	53.518
5	2.5	3.795	14.462	0.796	-26.8633	34.4533
	0.5	5.5125	14.462	0.708	-25.1458	36.1708
	0.05	20.3575	14.462	0.178	-10.3008	51.0158
	0	28.228	13.72	0.056	-0.857	57.313

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-21.79050*	9.333	0.033	-41.5755	-2.0055
	2.5	-28.10050*	9.333	0.008	-47.8855	-8.3155
	0.5	-20.14300*	9.333	0.046	-39.928	-0.358
	0.05	-23.49050*	9.333	0.023	-43.2755	-3.7055
0.05	5	1.7	9.8378	0.865	-19.1553	22.5553
	2.5	-4.61	9.8378	0.646	-25.4653	16.2453
	0.5	3.3475	9.8378	0.738	-17.5078	24.2028
	0	23.49050*	9.333	0.023	3.7055	43.2755
0.5	5	-1.6475	9.8378	0.869	-22.5028	19.2078
	2.5	-7.9575	9.8378	0.43	-28.8128	12.8978
	0.05	-3.3475	9.8378	0.738	-24.2028	17.5078
	0	20.14300*	9.333	0.046	0.358	39.928
2.5	5	6.31	9.8378	0.53	-14.5453	27.1653

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	0.5	7.9575	9.8378	0.43	-12.8978	28.8128
	0.05	4.61	9.8378	0.646	-16.2453	25.4653
	0	28.10050*	9.333	0.008	8.3155	47.8855
5	2.5	-6.31	9.8378	0.53	-27.1653	14.5453
	0.5	1.6475	9.8378	0.869	-19.2078	22.5028
	0.05	-1.7	9.8378	0.865	-22.5553	19.1553
	0	21.79050*	9.333	0.033	2.0055	41.5755

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-33.19800*	7.4273	0	-48.9431	-17.4529
	2.5	-22.31800*	7.4273	0.008	-38.0631	-6.5729
	0.5	-25.11050*	7.4273	0.004	-40.8556	-9.3654
	0.05	-26.15800*	7.4273	0.003	-41.9031	-10.4129
0.05	5	-7.04	7.829	0.382	-23.6368	9.5568
	2.5	3.84	7.829	0.63	-12.7568	20.4368
	0.5	1.0475	7.829	0.895	-15.5493	17.6443
	0	26.15800*	7.4273	0.003	10.4129	41.9031
0.5	5	-8.0875	7.829	0.317	-24.6843	8.5093
	2.5	2.7925	7.829	0.726	-13.8043	19.3893
	0.05	-1.0475	7.829	0.895	-17.6443	15.5493
	0	25.11050*	7.4273	0.004	9.3654	40.8556
2.5	5	-10.88	7.829	0.184	-27.4768	5.7168
	0.5	-2.7925	7.829	0.726	-19.3893	13.8043
	0.05	-3.84	7.829	0.63	-20.4368	12.7568
	0	22.31800*	7.4273	0.008	6.5729	38.0631
5	2.5	10.88	7.829	0.184	-5.7168	27.4768
	0.5	8.0875	7.829	0.317	-8.5093	24.6843
	0.05	7.04	7.829	0.382	-9.5568	23.6368
	0	33.19800*	7.4273	0	17.4529	48.9431

*The mean difference is significant at the .05 level.

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Outer bark (D) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-27.62800*	6.8717	0.001	-42.1953	-13.0607
	2.5	-29.67300*	6.8717	0.001	-44.2403	-15.1057
	0.5	-29.92550*	6.8717	0	-44.4928	-15.3582
	0.05	-29.73050*	6.8717	0.001	-44.2978	-15.1632
0.05	5	2.1025	7.2434	0.775	-13.2528	17.4578
	2.5	0.0575	7.2434	0.994	-15.2978	15.4128
	0.5	-0.195	7.2434	0.979	-15.5503	15.1603
	0	29.73050*	6.8717	0.001	15.1632	44.2978
0.5	5	2.2975	7.2434	0.755	-13.0578	17.6528
	2.5	0.2525	7.2434	0.973	-15.1028	15.6078
	0.05	0.195	7.2434	0.979	-15.1603	15.5503
	0	29.92550*	6.8717	0	15.3582	44.4928
2.5	5	2.045	7.2434	0.781	-13.3103	17.4003
	0.5	-0.2525	7.2434	0.973	-15.6078	15.1028
	0.05	-0.0575	7.2434	0.994	-15.4128	15.2978
	0	29.67300*	6.8717	0.001	15.1057	44.2403
5	2.5	-2.045	7.2434	0.781	-17.4003	13.3103
	0.5	-2.2975	7.2434	0.755	-17.6528	13.0578
	0.05	-2.1025	7.2434	0.775	-17.4578	13.2528
	0	27.62800*	6.8717	0.001	13.0607	42.1953

*The mean difference is significant at the .05 level.

Inner bark (E) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-30.35550*	8.2969	0.002	-47.9442	-12.7668
	2.5	-25.89800*	8.2969	0.007	-43.4867	-8.3093
	0.5	-23.95050*	8.2969	0.011	-41.5392	-6.3618
	0.05	-20.64300*	8.2969	0.024	-38.2317	-3.0543
0.05	5	-9.7125	8.7458	0.283	-28.2527	8.8277
	2.5	-5.255	8.7458	0.556	-23.7952	13.2852

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	0.5	-3.3075	8.7458	0.71	-21.8477	15.2327
	0	20.64300*	8.2969	0.024	3.0543	38.2317
0.5	5	-6.405	8.7458	0.475	-24.9452	12.1352
	2.5	-1.9475	8.7458	0.827	-20.4877	16.5927
	0.05	3.3075	8.7458	0.71	-15.2327	21.8477
	0	23.95050*	8.2969	0.011	6.3618	41.5392
2.5	5	-4.4575	8.7458	0.617	-22.9977	14.0827
	0.5	1.9475	8.7458	0.827	-16.5927	20.4877
	0.05	5.255	8.7458	0.556	-13.2852	23.7952
	0	25.89800*	8.2969	0.007	8.3093	43.4867
5	2.5	4.4575	8.7458	0.617	-14.0827	22.9977
	0.5	6.405	8.7458	0.475	-12.1352	24.9452
	0.05	9.7125	8.7458	0.283	-8.8277	28.2527
	0	30.35550*	8.2969	0.002	12.7668	47.9442

*The mean difference is significant at the .05 level.

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Appendix III: Results for maize grain weight loss caused *S. zeamais* at 30 days post treatment

Table 14. Analysis of variance for percent maize grain weight loss caused by *S. zeamais* treated with *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E).

Anova for leaves powder (A) treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-Value
Treatments	490.64	4	122.66	50.976**
Error	38.5	16	2.406	
Total	529.14	20		

Anova for seed powder (B) treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	501.536	4	125.384	15.582*
Error	128.75	16	8.047	
Total	630.286	20		

Anova for root powder (C) treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	375.571	4	93.893	12.624*
Error	119	16	7.438	
Total	494.571	20		

Anova for outer bark powder (D) treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	582.167	4	145.542	12.354*
Error	188.5	16	11.781	
Total	770.667	20		

Anova for inner bark (E) treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	703.917	4	175.979	97.936**
Error	28.75	16	1.797	
Total	732.667	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 15. LSD post hoc multiple comparisons of mean maize grain weight loss caused by *S. zeamais* treated with *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 30 days post treatment.

Leaves powder (A) treatment multiple comparisons

(I) Dose	(J) Dose	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	11.75000*	1.04058	0	9.5441	13.9559
	2.5	11.50000*	1.04058	0	9.2941	13.7059
	0.5	10.00000*	1.04058	0	7.7941	12.2059
	0.05	11.75000*	1.04058	0	9.5441	13.9559
0.05	5	0	1.09687	1	-2.3253	2.3253
	2.5	-0.25	1.09687	0.823	-2.5753	2.0753
	0.5	-1.75	1.09687	0.13	-4.0753	0.5753
	0	-11.75000*	1.04058	0	-13.9559	-9.5441
0.5	5	1.75	1.09687	0.13	-0.5753	4.0753
	2.5	1.5	1.09687	0.19	-0.8253	3.8253
	0.05	1.75	1.09687	0.13	-0.5753	4.0753
	0	-10.00000*	1.04058	0	-12.2059	-7.7941
2.5	5	0.25	1.09687	0.823	-2.0753	2.5753
	0.5	-1.5	1.09687	0.19	-3.8253	0.8253
	0.05	0.25	1.09687	0.823	-2.0753	2.5753
	0	-11.50000*	1.04058	0	-13.7059	-9.2941
5	2.5	-0.25	1.09687	0.823	-2.5753	2.0753
	0.5	-1.75	1.09687	0.13	-4.0753	0.5753
	0.05	0	1.09687	1	-2.3253	2.3253
	0	-11.75000*	1.04058	0	-13.9559	-9.5441

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

(I) Dose	(J) Dose	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	12.00000*	1.90292	0	7.966	16.034
	2.5	11.50000*	1.90292	0	7.466	15.534
	0.5	11.50000*	1.90292	0	7.466	15.534

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	0.05	10.75000*	1.90292	0	6.716	14.784
0.05	5	1.25	2.00585	0.542	-3.0022	5.5022
	2.5	0.75	2.00585	0.713	-3.5022	5.0022
	0.5	0.75	2.00585	0.713	-3.5022	5.0022
	0	-10.75000*	1.90292	0	-14.784	-6.716
0.5	5	0.5	2.00585	0.806	-3.7522	4.7522
	2.5	0	2.00585	1	-4.2522	4.2522
	0.05	-0.75	2.00585	0.713	-5.0022	3.5022
	0	-11.50000*	1.90292	0	-15.534	-7.466
2.5	5	0.5	2.00585	0.806	-3.7522	4.7522
	0.5	0	2.00585	1	-4.2522	4.2522
	0.05	-0.75	2.00585	0.713	-5.0022	3.5022
	0	-11.50000*	1.90292	0	-15.534	-7.466
5	2.5	-0.5	2.00585	0.806	-4.7522	3.7522
	0.5	-0.5	2.00585	0.806	-4.7522	3.7522
	0.05	-1.25	2.00585	0.542	-5.5022	3.0022
	0	-12.00000*	1.90292	0	-16.034	-7.966

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

(I) Dose	(J) Dose	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	12.50000*	2.30251	0	7.6189	17.3811
	2.5	11.00000*	2.30251	0	6.1189	15.8811
	0.5	12.25000*	2.30251	0	7.3689	17.1311
	0.05	13.25000*	2.30251	0	8.3689	18.1311
0.05	5	-0.75	2.42706	0.761	-5.8951	4.3951
	2.5	-2.25	2.42706	0.368	-7.3951	2.8951
	0.5	-1	2.42706	0.686	-6.1451	4.1451
	0	-13.25000*	2.30251	0	-18.1311	-8.3689
0.5	5	0.25	2.42706	0.919	-4.8951	5.3951
	2.5	-1.25	2.42706	0.614	-6.3951	3.8951
	0.05	1	2.42706	0.686	-4.1451	6.1451
	0	-12.25000*	2.30251	0	-17.1311	-7.3689
2.5	5	1.5	2.42706	0.545	-3.6451	6.6451

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	0.5	1.25	2.42706	0.614	-3.8951	6.3951
	0.05	2.25	2.42706	0.368	-2.8951	7.3951
	0	-11.00000*	2.30251	0	-15.8811	-6.1189
5	2.5	-1.5	2.42706	0.545	-6.6451	3.6451
	0.5	-0.25	2.42706	0.919	-5.3951	4.8951
	0.05	0.75	2.42706	0.761	-4.3951	5.8951
	0	-12.50000*	2.30251	0	-17.3811	-7.6189

*The mean difference is significant at the .05 level.

Outer bark powder (D) treatment multiple comparisons

(I) Dose	(J) Dose	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	11.75000*	1.82945	0	7.8717	15.6283
	2.5	9.25000*	1.82945	0	5.3717	13.1283
	0.5	9.25000*	1.82945	0	5.3717	13.1283
	0.05	7.25000*	1.82945	0.001	3.3717	11.1283
0.05	5	4.50000*	1.92841	0.033	0.412	8.588
	2.5	2	1.92841	0.315	-2.088	6.088
	0.5	2	1.92841	0.315	-2.088	6.088
	0	-7.25000*	1.82945	0.001	-11.1283	-3.3717
0.5	5	2.5	1.92841	0.213	-1.588	6.588
	2.5	0	1.92841	1	-4.088	4.088
	0.05	-2	1.92841	0.315	-6.088	2.088
	0	-9.25000*	1.82945	0	-13.1283	-5.3717
2.5	5	2.5	1.92841	0.213	-1.588	6.588
	0.5	0	1.92841	1	-4.088	4.088
	0.05	-2	1.92841	0.315	-6.088	2.088
	0	-9.25000*	1.82945	0	-13.1283	-5.3717
5	2.5	-2.5	1.92841	0.213	-6.588	1.588
	0.5	-2.5	1.92841	0.213	-6.588	1.588
	0.05	-4.50000*	1.92841	0.033	-8.588	-0.412
	0	-11.75000*	1.82945	0	-15.6283	-7.8717

*The mean difference is significant at the .05 level.

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Inner bark powder (E) treatment multiple comparisons

(I) Dose	(J) Dose	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0g	5	13.00000*	0.89922	0	11.0937	14.9063
	2.5	14.00000*	0.89922	0	12.0937	15.9063
	0.5	14.00000*	0.89922	0	12.0937	15.9063
	0.05	13.25000*	0.89922	0	11.3437	15.1563
0.05	5	-0.25	0.94786	0.795	-2.2594	1.7594
	2.5	0.75	0.94786	0.44	-1.2594	2.7594
	0.5	0.75	0.94786	0.44	-1.2594	2.7594
	0	-13.25000*	0.89922	0	-15.1563	-11.344
0.5	5	-1	0.94786	0.307	-3.0094	1.0094
	2.5	0	0.94786	1	-2.0094	2.0094
	0.05	-0.75	0.94786	0.44	-2.7594	1.2594
	0	-14.00000*	0.89922	0	-15.9063	-12.094
2.5	5	-1	0.94786	0.307	-3.0094	1.0094
	0.5	0	0.94786	1	-2.0094	2.0094
	0.05	-0.75	0.94786	0.44	-2.7594	1.2594
	0	-14.00000*	0.89922	0	-15.9063	-12.094
5	2.5	1	0.94786	0.307	-1.0094	3.0094
	0.5	1	0.94786	0.307	-1.0094	3.0094
	0.05	0.25	0.94786	0.795	-1.7594	2.2594
	0	-13.00000*	0.89922	0	-14.9063	-11.094

*The mean difference is significant at the .05 level.

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Appendix IV: Results for maize grain weight loss caused by *S. zeamais* at 60 and 90 days post treatment

Table 16. Analysis of variance of maize grain weight loss caused by *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E) powders at 60 day post treatment.

Anova for leave (A) powder treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-Value
Treatments	853.361	4	213.34	31.275**
Error	109.142	16	6.821	
Total	962.503	20		

Anova for seed (B) powder

Source of Variation	Sum of Squares	Df	Mean Square	F-Value
Treatments	670.77	4	167.693	23.17**
Error	115.802	16	7.238	
Total	786.572	20		

Anova for root (C) powder treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	2151.139	4	537.785	89.781**
Error	95.84	16	5.99	
Total	2246.978	20		

Anova for outer bark (D) powder treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	2044.33	4	511.082	104.966**
Error	77.905	16	4.869	
Total	2122.23	20		

Anova for inner bark (E) powder treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	1041.41	4	260.353	28.806**
Error	144.612	16	9.038	
Total	1186.02	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 17. Analysis of variance of maize grain weight loss caused by *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E) powders at 90 days post treatment.

Anova for leave (A) powder treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	1974.09	4	493.521	3.169*
Error	2491.76	16	155.735	
Total	4465.85	20		

Anova for seed (B) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	1513.252	4	378.313	3.313*
Error	1827.26	16	114.204	
Total	3340.512	20		

Anova for root (C) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	4864.61	4	1216.152	14.823**
Error	1312.76	16	82.048	
Total	6177.37	20		

Anova for outer bark (D) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value	
Treatments	3657.002	4	914.251	6.483	0.003 ^{NS}
Error	2256.51	16	141.032		
Total	5913.512	20			

Anova for inner bark (E) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	383.467	4	95.867	0.848*
Error	1808.76	16	113.048	
Total	2192.227	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 18. LSD post hoc multiple comparisons of maize grain weight loss caused by *S. zeamais* treated with *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 60 days post treatment

Leave powder (A) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	19.04000*	1.75	0	15.3259	22.7541
	2.5	6.04000*	1.75	0.003	2.3259	9.7541
	0.5	7.54000*	1.75	0.001	3.8259	11.2541
	0.05	10.79000*	1.75	0	7.0759	14.5041
0.05	5	8.25000*	1.85	0	4.3349	12.1651
	2.5	-4.75000*	1.85	0.02	-8.6651	-0.8349
	0.5	-3.25	1.85	0.098	-7.1651	0.6651
	0	-10.79000*	1.75	0	-14.504	-7.0759
0.5	5	11.50000*	1.85	0	7.5849	15.4151
	2.5	-1.5	1.85	0.429	-5.4151	2.4151
	0.05	3.25	1.85	0.098	-0.6651	7.1651
	0	-7.54000*	1.75	0.001	-11.254	-3.8259
2.5	5	13.00000*	1.85	0	9.0849	16.9151
	0.5	1.5	1.85	0.429	-2.4151	5.4151
	0.05	4.75000*	1.85	0.02	0.8349	8.6651
	0	-6.04000*	1.75	0.003	-9.7541	-2.3259
5	2.5	-13.00000*	1.85	0	-16.915	-9.0849
	0.5	-11.50000*	1.85	0	-15.415	-7.5849
	0.05	-8.25000*	1.85	0	-12.165	-4.3349
	0	-19.04000*	1.75	0	-22.754	-15.326

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	15.74000*	1.8	0	11.9142	19.5658

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	2.5	13.24000*	1.8	0	9.4142	17.0658
	0.5	10.79000*	1.8	0	6.9642	14.6158
	0.05	10.04000*	1.8	0	6.2142	13.8658
0.05	5	5.70000*	1.9	0.009	1.6673	9.7327
	2.5	3.2	1.9	0.112	-0.8327	7.2327
	0.5	0.75	1.9	0.699	-3.2827	4.7827
	0	-10.04000*	1.8	0	-13.866	-6.2142
0.5	5	4.95000*	1.9	0.019	0.9173	8.9827
	2.5	2.45	1.9	0.216	-1.5827	6.4827
	0.05	-0.75	1.9	0.699	-4.7827	3.2827
	0	-10.79000*	1.8	0	-14.616	-6.9642
2.5	5	2.5	1.9	0.207	-1.5327	6.5327
	0.5	-2.45	1.9	0.216	-6.4827	1.5827
	0.05	-3.2	1.9	0.112	-7.2327	0.8327
	0	-13.24000*	1.8	0	-17.066	-9.4142
5	2.5	-2.5	1.9	0.207	-6.5327	1.5327
	0.5	-4.95000*	1.9	0.019	-8.9827	-0.9173
	0.05	-5.70000*	1.9	0.009	-9.7327	-1.6673
	0	-15.74000*	1.8	0	-19.566	-11.914

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	28.82*	1.64	0	25.3346	32.2954
	2.5	22.29*	1.64	0	18.8096	25.7704
	0.5	20.04*	1.64	0	16.5596	23.5204
	0.05	16.79*	1.64	0	13.3096	20.2704
0.05	5	12.03*	1.73	0	8.3563	15.6937
	2.5	5.50*	1.73	0.006	1.8313	9.1687
	0.5	3.25	1.73	0.079	-0.4187	6.9187
	0	-16.79*	1.64	0	-20.27	-13.31
0.5	5	8.78*	1.73	0	5.1063	12.4437
	2.5	2.25	1.73	0.212	-1.4187	5.9187
	0.05	-3.25	1.73	0.079	-6.9187	0.4187

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	0	-20.04*	1.64	0	-23.52	-16.56
2.5	5	6.53*	1.73	0.002	2.8563	10.1937
	0.5	-2.25	1.73	0.212	-5.9187	1.4187
	0.05	-5.50*	1.73	0.006	-9.1687	-1.8313
	0	-22.29*	1.64	0	-25.77	-18.81
5	2.5	-6.53*	1.73	0.002	-10.194	-2.8563
	0.5	-8.77500*	1.73	0	-12.444	-5.1063
	0.05	-12.02*	1.73	0	-15.694	-8.3563
	0	-28.82*	1.64	0	-32.295	-25.335

*The mean difference is significant at the .05 level.

Outer bark (D) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	28.31500*	1.48	0	25.1771	31.4529
	2.5	21.01500*	1.48	0	17.8771	24.1529
	0.5	19.79000*	1.48	0	16.6521	22.9279
	0.05	16.76500*	1.48	0	13.6271	19.9029
0.05	5	11.55000*	1.56	0	8.2423	14.8577
	2.5	4.25000*	1.56	0.015	0.9423	7.5577
	0.5	3.025	1.56	0.07	-0.2827	6.3327
	0	-16.76500*	1.48	0	-19.903	-13.627
0.5	5	8.52500*	1.56	0	5.2173	11.8327
	2.5	1.225	1.56	0.444	-2.0827	4.5327
	0.05	-3.025	1.56	0.07	-6.3327	0.2827
	0	-19.79000*	1.48	0	-22.928	-16.652
2.5	5	7.30000*	1.56	0	3.9923	10.6077
	0.5	-1.225	1.56	0.444	-4.5327	2.0827
	0.05	-4.25000*	1.56	0.015	-7.5577	-0.9423
	0	-21.01500*	1.48	0	-24.153	-17.877
5	2.5	-7.30000*	1.56	0	-10.608	-3.9923
	0.5	-8.52500*	1.56	0	-11.833	-5.2173
	0.05	-11.55000*	1.56	0	-14.858	-8.2423
	0	-28.31500*	1.48	0	-31.453	-25.177

*The mean difference is significant at the .05 level.

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Inner bark (E) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	18.54000*	2.02	0	14.2647	22.8153
	2.5	16.29000*	2.02	0	12.0147	20.5653
	0.5	15.29000*	2.02	0	11.0147	19.5653
	0.05	15.04000*	2.02	0	10.7647	19.3153
0.05	5	3.5	2.13	0.119	-1.0065	8.0065
	2.5	1.25	2.13	0.565	-3.2565	5.7565
	0.5	0.25	2.13	0.908	-4.2565	4.7565
	0	-15.04000*	2.02	0	-19.315	-10.765
0.5	5	3.25	2.13	0.146	-1.2565	7.7565
	2.5	1	2.13	0.644	-3.5065	5.5065
	0.05	-0.25	2.13	0.908	-4.7565	4.2565
	0	-15.29000*	2.02	0	-19.565	-11.015
2.5	5	2.25	2.13	0.306	-2.2565	6.7565
	0.5	-1	2.13	0.644	-5.5065	3.5065
	0.05	-1.25	2.13	0.565	-5.7565	3.2565
	0	-16.29000*	2.02	0	-20.565	-12.015
5	2.5	-2.25	2.13	0.306	-6.7565	2.2565
	0.5	-3.25	2.13	0.146	-7.7565	1.2565
	0.05	-3.5	2.13	0.119	-8.0065	1.0065
	0	-18.54000*	2.02	0	-22.815	-14.265

*The mean difference is significant at the .05 level.

Table 19. LSD post hoc multiple comparisons maize grain weight loss caused by *S. zeamais* treated with *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 90 days post treatment

Leave powder (A) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Differenc e (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	22.10*	8.37142	0.018	4.3534	39.8466
	2.5	22.10*	8.37142	0.018	4.3534	39.8466
	0.5	23.10*	8.37142	0.014	5.3534	40.8466

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	0.05	23.60000*	8.37142	0.012	5.8534	41.3466
0.05	5	-1.5	8.82426	0.867	-20.207	17.2066
	2.5	-1.5	8.82426	0.867	-20.207	17.2066
	0.5	-0.5	8.82426	0.956	-19.207	18.2066
	0	-23.60*	8.37142	0.012	-41.347	-5.8534
0.5	5	-1	8.82426	0.911	-19.707	17.7066
	2.5	-1	8.82426	0.911	-19.707	17.7066
	0.05	0.5	8.82426	0.956	-18.207	19.2066
	0	-23.10*	8.37142	0.014	-40.847	-5.3534
2.5	5	0	8.82426	1	-18.707	18.7066
	0.5	1	8.82426	0.911	-17.707	19.7066
	0.05	1.5	8.82426	0.867	-17.207	20.2066
	0	-22.10*	8.37142	0.018	-39.847	-4.3534
5	2.5	0	8.82426	1	-18.707	18.7066
	0.5	1	8.82426	0.911	-17.707	19.7066
	0.05	1.5	8.82426	0.867	-17.207	20.2066
	0	-22.10*	8.37142	0.018	-39.847	-4.3534

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	22.60*	7.17	0.006	7.4028	37.7972
	2.5	14.85	7.17	0.055	-0.3472	30.0472
	0.5	19.85*	7.17	0.014	4.6528	35.0472
	0.05	19.10*	7.17	0.017	3.9028	34.2972
0.05	5	3.5	7.56	0.649	-12.519	19.5192
	2.5	-4.25	7.56	0.582	-20.269	11.7692
	0.5	0.75	7.56	0.922	-15.269	16.7692
	0	-19.1*	7.17	0.017	-34.297	-3.9028
0.5	5	2.75	7.56	0.721	-13.269	18.7692
	2.5	-5	7.56	0.518	-21.019	11.0192
	0.05	-0.75	7.56	0.922	-16.769	15.2692
	0	-19.85*	7.17	0.014	-35.047	-4.6528

2.5	5	7.75	7.56	0.32	-8.2692	23.7692
	0.5	5	7.56	0.518	-11.019	21.0192
	0.05	4.25	7.56	0.582	-11.769	20.2692
	0	-14.85	7.17	0.055	-30.047	0.3472
5	2.5	-7.75	7.56	0.32	-23.769	8.2692
	0.5	-2.75	7.56	0.721	-18.769	13.2692
	0.05	-3.5	7.56	0.649	-19.519	12.5192
	0	-22.60*	7.17	0.006	-37.797	-7.4028

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	41.60*	6.08	0	28.7188	54.4812
	2.5	33.60*	6.08	0	20.7188	46.4812
	0.5	33.60*	6.08	0	20.7188	46.4812
	0.05	21.60*	6.08	0.003	8.7188	34.4812
0.05	5	20.00*	6.4	0.007	6.4221	33.5779
	2.5	12	6.4	0.079	-1.5779	25.5779
	0.5	12	6.4	0.079	-1.5779	25.5779
	0	-21.60*	6.08	0.003	-34.481	-8.7188
0.5	5	8	6.4	0.23	-5.5779	21.5779
	2.5	0	6.4	1	-13.578	13.5779
	0.05	-12	6.4	0.079	-25.578	1.5779
	0	-33.60*	6.08	0	-46.481	-20.719
2.5	5	8	6.4	0.23	-5.5779	21.5779
	0.5	0	6.4	1	-13.578	13.5779
	0.05	-12	6.4	0.079	-25.578	1.5779
	0	-33.60*	6.08	0	-46.481	-20.719
5	2.5	-8	6.4	0.23	-21.578	5.5779
	0.5	-8	6.4	0.23	-21.578	5.5779
	0.05	-20.00*	6.4	0.007	-33.578	-6.4221
	0	-41.60*	6.08	0	-54.481	-28.719

*The mean difference is significant at the .05 level.

Outer bark (D) powder treatment multiple comparisons

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Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	38.35*	7.97	0	21.4619	55.2381
	2.5	27.10*	7.97	0.004	10.2119	43.9881
	0.5	26.10*	7.97	0.005	9.2119	42.9881
	0.05	21.60*	7.97	0.015	4.7119	38.4881
0.05	5	16.75	8.4	0.063	-1.0516	34.5516
	2.5	5.5	8.4	0.522	-12.302	23.3016
	0.5	4.5	8.4	0.599	-13.302	22.3016
	0	-21.60*	7.97	0.015	-38.488	-4.7119
0.5	5	12.25	8.4	0.164	-5.5516	30.0516
	2.5	1	8.4	0.907	-16.802	18.8016
	0.05	-4.5	8.4	0.599	-22.302	13.3016
	0	-26.10*	7.97	0.005	-42.988	-9.2119
2.5	5	11.25	8.4	0.199	-6.5516	29.0516
	0.5	-1	8.4	0.907	-18.802	16.8016
	0.05	-5.5	8.4	0.522	-23.302	12.3016
	0	-27.10*	7.97	0.004	-43.988	-10.212
5	2.5	-11.25	8.4	0.199	-29.052	6.5516
	0.5	-12.25	8.4	0.164	-30.052	5.5516
	0.05	-16.75	8.4	0.063	-34.552	1.0516
	0	-38.35*	7.97	0	-55.238	-21.462

*The mean difference is significant at the .05 level.

Inner bark (E) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	7.6	7.13	0.302	-7.52	22.72
	2.5	11.6	7.13	0.123	-3.52	26.72
	0.5	6.6	7.13	0.369	-8.52	21.72
	0.05	10.6	7.13	0.157	-4.52	25.72
0.05	5	-3	7.52	0.695	-18.938	12.9379
	2.5	1	7.52	0.896	-14.938	16.9379
	0.5	-4	7.52	0.602	-19.938	11.9379

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	0	-10.6	7.13	0.157	-25.72	4.52
0.5	5	1	7.52	0.896	-14.938	16.9379
	2.5	5	7.52	0.515	-10.938	20.9379
	0.05	4	7.52	0.602	-11.938	19.9379
	0	-6.6	7.13	0.369	-21.72	8.52
2.5	5	-4	7.52	0.602	-19.938	11.9379
	0.5	-5	7.52	0.515	-20.938	10.9379
	0.05	-1	7.52	0.896	-16.938	14.9379
	0	-11.6	7.13	0.123	-26.72	3.52
5	2.5	4	7.52	0.602	-11.938	19.9379
	0.5	-1	7.52	0.896	-16.938	14.9379
	0.05	3	7.52	0.695	-12.938	18.9379
	0	-7.6	7.13	0.302	-22.72	7.52

*The mean difference is significant at the .05 level.

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Appendix V: Results for adult emergence of *S. zeamais* treated with plant powder against S. zeamais at 60 and 90 days post treatment

Table 20. Analysis of variance of adult emergence of *S. zeamais* caused by *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E) powders at 60 day post treatment.

Anova for leave (A) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-Value
Treatments	1431.18	4	357.794	35.309**
Error	162.133	16	10.133	
Total	1593.31	20		

Anova for seed (B) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-Value
Treatments	841.793	4	210.448	13.985**
Error	240.773	16	15.048	
Total	1082.57	20		

Anova for root (C) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	3145.66	4	786.414	56.272**
Error	223.603	16	13.975	
Total	3369.26	20		

Anova for outer bark (D) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	2625.96	4	656.491	62.986**
Error	166.765	16	10.423	
Total	2792.73	20		

Anova for inner bark (E) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	1670.3	4	417.575	41.104**
Error	162.545	16	10.159	
Total	1832.85	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 21. Analysis of variance of adult emergence of *S. zeamais* caused by *S. africana* leaves (A), seed (B), root (C), outer bark (D) and inner bark (E) powders at 90 day post treatment.

Anova for leave (A) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	2417.74	4	604.434	2.044*
Error	4730.55	16	295.659	
Total	7148.29	20		

Anova for seed (B) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	128.76	4	32.19	0.597*
Error	863.05	16	53.941	
Total	991.81	20		

Anova for root (C) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	2270.188	4	567.547	1.785*
Error	5087.05	16	317.941	
Total	7357.238	20		

Anova for outer bark (D) powder treatment

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	1489.117	4	372.279	0.741*
Error	8035.55	16	502.222	
Total	9524.667	20		

Anova for inner bark (E) powder treatment

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	121.271	4	30.318	1.168*
Error	415.3	16	25.956	
Total	536.571	20		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 22. LSD post hoc multiple comparisons of adult emergence of *S. zeamais* at treated with *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 60 days post treatment

Leave powder (A) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	24.35500*	2.1354	0	19.8281	28.8819
	2.5	15.88000*	2.1354	0	11.3531	20.4069
	0.5	14.03000*	2.1354	0	9.5031	18.5569
	0.05	16.00500*	2.1354	0	11.4781	20.5319
0.05	5	8.35000*	2.2509	0.002	3.5783	13.1217
	2.5	-0.125	2.2509	0.956	-4.8967	4.6467
	0.5	-1.975	2.2509	0.393	-6.7467	2.7967
	0	-16.00500*	2.1354	0	-20.5319	-11.4781
0.5	5	10.32500*	2.2509	0	5.5533	15.0967
	2.5	1.85	2.2509	0.423	-2.9217	6.6217
	0.05	1.975	2.2509	0.393	-2.7967	6.7467
	0	-14.03000*	2.1354	0	-18.5569	-9.5031
2.5	5	8.47500*	2.2509	0.002	3.7033	13.2467
	0.5	-1.85	2.2509	0.423	-6.6217	2.9217
	0.05	0.125	2.2509	0.956	-4.6467	4.8967
	0	-15.88000*	2.1354	0	-20.4069	-11.3531
5	2.5	-8.47500*	2.2509	0.002	-13.2467	-3.7033
	0.5	-10.32500*	2.2509	0	-15.0967	-5.5533
	0.05	-8.35000*	2.2509	0.002	-13.1217	-3.5783
	0	-24.35500*	2.1354	0	-28.8819	-19.8281

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

(I) Dose	(J) Dose	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	16.38000*	2.6023	0	10.8635	21.8965
	2.5	10.63000*	2.6023	0.001	5.1135	16.1465
	0.5	13.70500*	2.6023	0	8.1885	19.2215

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	0.05	15.80500*	2.6023	0	10.2885	21.3215
0.05	5	0.575	2.743	0.837	-5.2399	6.3899
	2.5	-5.175	2.743	0.077	-10.9899	0.6399
	0.5	-2.1	2.743	0.455	-7.9149	3.7149
	0	-15.80500*	2.6023	0	-21.3215	-10.2885
0.5	5	2.675	2.743	0.344	-3.1399	8.4899
	2.5	-3.075	2.743	0.279	-8.8899	2.7399
	0.05	2.1	2.743	0.455	-3.7149	7.9149
	0	-13.70500*	2.6023	0	-19.2215	-8.1885
2.5	5	5.75	2.743	0.052	-0.0649	11.5649
	0.5	3.075	2.743	0.279	-2.7399	8.8899
	0.05	5.175	2.743	0.077	-0.6399	10.9899
	0	-10.63000*	2.6023	0.001	-16.1465	-5.1135
5	2.5	-5.75	2.743	0.052	-11.5649	0.0649
	0.5	-2.675	2.743	0.344	-8.4899	3.1399
	0.05	-0.575	2.743	0.837	-6.3899	5.2399
	0	-16.38000*	2.6023	0	-21.8965	-10.8635

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	34.48000*	2.5078	0	29.1638	39.7962
	2.5	27.10500*	2.5078	0	21.7888	32.4212
	0.5	24.98000*	2.5078	0	19.6638	30.2962
	0.05	21.95500*	2.5078	0	16.6388	27.2712
0.05	5	12.52500*	2.6434	0	6.9212	18.1288
	2.5	5.15	2.6434	0.069	-0.4538	10.7538
	0.5	3.025	2.6434	0.269	-2.5788	8.6288
	0	-21.95500*	2.5078	0	-27.2712	-16.6388
0.5	5	9.50000*	2.6434	0.002	3.8962	15.1038
	2.5	2.125	2.6434	0.433	-3.4788	7.7288
	0.05	-3.025	2.6434	0.269	-8.6288	2.5788
	0	-24.98000*	2.5078	0	-30.2962	-19.6638
2.5	5	7.37500*	2.6434	0.013	1.7712	12.9788

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	0.5	-2.125	2.6434	0.433	-7.7288	3.4788
	0.05	-5.15	2.6434	0.069	-10.7538	0.4538
	0	-27.10500*	2.5078	0	-32.4212	-21.7888
5	2.5	-7.37500*	2.6434	0.013	-12.9788	-1.7712
	0.5	-9.50000*	2.6434	0.002	-15.1038	-3.8962
	0.05	-12.52500*	2.6434	0	-18.1288	-6.9212
	0	-34.48000*	2.5078	0	-39.7962	-29.1638

*The mean difference is significant at the .05 level.

Outer bark (D) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	30.78000*	2.1657	0	26.1889	35.3711
	2.5	23.78000*	2.1657	0	19.1889	28.3711
	0.5	25.30500*	2.1657	0	20.7139	29.8961
	0.05	21.03000*	2.1657	0	16.4389	25.6211
0.05	5	9.75000*	2.2829	0.001	4.9106	14.5894
	2.5	2.75	2.2829	0.246	-2.0894	7.5894
	0.5	4.275	2.2829	0.08	-0.5644	9.1144
	0	-21.03000*	2.1657	0	-25.6211	-16.4389
0.5	5	5.47500*	2.2829	0.029	0.6356	10.3144
	2.5	-1.525	2.2829	0.514	-6.3644	3.3144
	0.05	-4.275	2.2829	0.08	-9.1144	0.5644
	0	-25.30500*	2.1657	0	-29.8961	-20.7139
2.5	5	7.00000*	2.2829	0.007	2.1606	11.8394
	0.5	1.525	2.2829	0.514	-3.3144	6.3644
	0.05	-2.75	2.2829	0.246	-7.5894	2.0894
	0	-23.78000*	2.1657	0	-28.3711	-19.1889
5	2.5	-7.00000*	2.2829	0.007	-11.8394	-2.1606
	0.5	-5.47500*	2.2829	0.029	-10.3144	-0.6356
	0.05	-9.75000*	2.2829	0.001	-14.5894	-4.9106
	0	-30.78000*	2.1657	0	-35.3711	-26.1889

*The mean difference is significant at the .05 level.

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Inner bark (E) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	23.53000*	2.1381	0	18.9974	28.0626
	2.5	20.95500*	2.1381	0	16.4224	25.4876
	0.5	19.28000*	2.1381	0	14.7474	23.8126
	0.05	18.48000*	2.1381	0	13.9474	23.0126
0.05	5	5.05000*	2.2538	0.04	0.2722	9.8278
	2.5	2.475	2.2538	0.288	-2.3028	7.2528
	0.5	0.8	2.2538	0.727	-3.9778	5.5778
	0	-18.48000*	2.1381	0	-23.0126	-13.9474
0.5	5	4.25	2.2538	0.078	-0.5278	9.0278
	2.5	1.675	2.2538	0.468	-3.1028	6.4528
	0.05	-0.8	2.2538	0.727	-5.5778	3.9778
	0	-19.28000*	2.1381	0	-23.8126	-14.7474
2.5	5	2.575	2.2538	0.27	-2.2028	7.3528
	0.5	-1.675	2.2538	0.468	-6.4528	3.1028
	0.05	-2.475	2.2538	0.288	-7.2528	2.3028
	0	-20.95500*	2.1381	0	-25.4876	-16.4224
5	2.5	-2.575	2.2538	0.27	-7.3528	2.2028
	0.5	-4.25	2.2538	0.078	-9.0278	0.5278
	0.05	-5.05000*	2.2538	0.04	-9.8278	-0.2722
	0	-23.53000*	2.1381	0	-28.0626	-18.9974

*The mean difference is significant at the .05 level.

Table 23. LSD post hoc multiple comparisons of adult emergence of *S. zeamais* treated with *S. africana* leave (A), seed (B), root (C), inner bark (D), Outer bark (E) powders, at 90 days post treatment

Leave powder (A) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	11.8	15.0333	0.444	-20.069	43.669
	2.5	3.8	15.0333	0.804	-28.069	35.669
	0.5	22.8	15.0333	0.149	-9.0692	54.669

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	0.05	16.55	15.0333	0.287	-15.319	48.419
0.05	5	-4.75	15.8465	0.768	-38.343	28.843
	2.5	-12.75	15.8465	0.433	-46.343	20.843
	0.5	6.25	15.8465	0.698	-27.343	39.843
	0	-16.55	15.0333	0.287	-48.419	15.319
0.5	5	-11	15.8465	0.498	-44.593	22.593
	2.5	-19	15.8465	0.248	-52.593	14.593
	0.05	-6.25	15.8465	0.698	-39.843	27.343
	0	-22.8	15.0333	0.149	-54.669	9.0692
2.5	5	8	15.8465	0.621	-25.593	41.593
	0.5	19	15.8465	0.248	-14.593	52.593
	0.05	12.75	15.8465	0.433	-20.843	46.343
	0	-3.8	15.0333	0.804	-35.669	28.069
5	2.5	-8	15.8465	0.621	-41.593	25.593
	0.5	11	15.8465	0.498	-22.593	44.593
	0.05	4.75	15.8465	0.768	-28.843	38.343
	0	-11.8	15.0333	0.444	-43.669	20.069

*The mean difference is significant at the .05 level.

Seed powder (B) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	3.8	4.92679	0.452	-6.6443	14.2443
	2.5	-2.45	4.92679	0.626	-12.8943	7.9943
	0.5	-3.45	4.92679	0.494	-13.8943	6.9943
	0.05	0.55	4.92679	0.913	-9.8943	10.9943
0.05	5	3.25	5.19329	0.54	-7.7593	14.2593
	2.5	-3	5.19329	0.572	-14.0093	8.0093
	0.5	-4	5.19329	0.452	-15.0093	7.0093
	0	-0.55	4.92679	0.913	-10.9943	9.8943
0.5	5	7.25	5.19329	0.182	-3.7593	18.2593
	2.5	1	5.19329	0.85	-10.0093	12.0093
	0.05	4	5.19329	0.452	-7.0093	15.0093
	0	3.45	4.92679	0.494	-6.9943	13.8943
2.5	5	6.25	5.19329	0.246	-4.7593	17.2593

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	0.5	-1	5.19329	0.85	-12.0093	10.0093
	0.05	3	5.19329	0.572	-8.0093	14.0093
	0	2.45	4.92679	0.626	-7.9943	12.8943
5	2.5	-6.25	5.19329	0.246	-17.2593	4.7593
	0.5	-7.25	5.19329	0.182	-18.2593	3.7593
	0.05	-3.25	5.19329	0.54	-14.2593	7.7593
	0	-3.8	4.92679	0.452	-14.2443	6.6443

*The mean difference is significant at the .05 level.

Root powder (C) treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	16.05	11.9613	0.198	-9.3069	41.4069
	2.5	12.8	11.9613	0.3	-12.5569	38.1569
	0.5	28.55000*	11.9613	0.03	3.1931	53.9069
	0.05	2.05	11.9613	0.866	-23.3069	27.4069
0.05	5	14	12.6083	0.283	-12.7285	40.7285
	2.5	10.75	12.6083	0.406	-15.9785	37.4785
	0.5	26.5	12.6083	0.052	-0.2285	53.2285
	0	-2.05	11.9613	0.866	-27.4069	23.3069
0.5	5	-12.5	12.6083	0.336	-39.2285	14.2285
	2.5	-15.75	12.6083	0.23	-42.4785	10.9785
	0.05	-26.5	12.6083	0.052	-53.2285	0.2285
	0	-28.5500*	11.9613	0.03	-53.9069	-3.1931
2.5	5	3.25	12.6083	0.8	-23.4785	29.9785
	0.5	15.75	12.6083	0.23	-10.9785	42.4785
	0.05	-10.75	12.6083	0.406	-37.4785	15.9785
	0	-12.8	11.9613	0.3	-38.1569	12.5569
5	2.5	-3.25	12.6083	0.8	-29.9785	23.4785
	0.5	12.5	12.6083	0.336	-14.2285	39.2285
	0.05	-14	12.6083	0.283	-40.7285	12.7285
	0	-16.05	11.9613	0.198	-41.4069	9.3069

*The mean difference is significant at the .05 level.

Outer bark (D) powder treatment multiple comparisons

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Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	11.8	15.0333	0.444	-20.0692	43.6692
	2.5	3.8	15.0333	0.804	-28.0692	35.6692
	0.5	22.8	15.0333	0.149	-9.0692	54.6692
	0.05	16.55	15.0333	0.287	-15.3192	48.4192
0.05	5	-4.75	15.8465	0.768	-38.343	28.843
	2.5	-12.75	15.8465	0.433	-46.343	20.843
	0.5	6.25	15.8465	0.698	-27.343	39.843
	0	-16.55	15.0333	0.287	-48.4192	15.3192
0.5	5	-11	15.8465	0.498	-44.593	22.593
	2.5	-19	15.8465	0.248	-52.593	14.593
	0.05	-6.25	15.8465	0.698	-39.843	27.343
	0	-22.8	15.0333	0.149	-54.6692	9.0692
2.5	5	8	15.8465	0.621	-25.593	41.593
	0.5	19	15.8465	0.248	-14.593	52.593
	0.05	12.75	15.8465	0.433	-20.843	46.343
	0	-3.8	15.0333	0.804	-35.6692	28.0692
5	2.5	-8	15.8465	0.621	-41.593	25.593
	0.5	11	15.8465	0.498	-22.593	44.593
	0.05	4.75	15.8465	0.768	-28.843	38.343
	0	-11.8	15.0333	0.444	-43.6692	20.0692

*The mean difference is significant at the .05 level.

Inner bark (E) powder treatment multiple comparisons

Dose I (g)	Dose J (g)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-6.45	3.41765	0.077	-13.6951	0.7951
	2.5	-3.95	3.41765	0.265	-11.1951	3.2951
	0.5	-5.2	3.41765	0.148	-12.4451	2.0451
	0.05	-5.7	3.41765	0.115	-12.9451	1.5451
0.05	5	-0.75	3.60252	0.838	-8.387	6.887
	2.5	1.75	3.60252	0.634	-5.887	9.387
	0.5	0.5	3.60252	0.891	-7.137	8.137

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	0	5.7	3.41765	0.115	-1.5451	12.9451
0.5	5	-1.25	3.60252	0.733	-8.887	6.387
	2.5	1.25	3.60252	0.733	-6.387	8.887
	0.05	-0.5	3.60252	0.891	-8.137	7.137
	0	5.2	3.41765	0.148	-2.0451	12.4451
2.5	5	-2.5	3.60252	0.498	-10.137	5.137
	0.5	-1.25	3.60252	0.733	-8.887	6.387
	0.05	-1.75	3.60252	0.634	-9.387	5.887
	0	3.95	3.41765	0.265	-3.2951	11.1951
5	2.5	2.5	3.60252	0.498	-5.137	10.137
	0.5	1.25	3.60252	0.733	-6.387	8.887
	0.05	0.75	3.60252	0.838	-6.887	8.387
	0	6.45	3.41765	0.077	-0.7951	13.6951

*The mean difference is significant at the .05 level.



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Appendix VI: Laboratory bioassays of *S. africana* crude extracts against *S. zeamais*

Table 24. Analysis of variance of mortality by contact toxicity of *S. zeamais* treated with *S. africana* root crude extracts.

Anova for root crude extracts treatment at 1 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	1600.000	3	533.333	1.818*
Error	10560.000	36	293.333	
Total	12160.000	39		

Anova for root crude extracts treatment at 24 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	5360.000	3	1786.667	3.573*
Error	18000.000	36	500.000	
Total	23360.000	39		

Anova for root crude extracts treatment at 48 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	8190.000	3	2730.000	4.865*
Error	20200.000	36	561.111	
Total	28390.000	39		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

Table 25. Analysis of variance of mortality by contact toxicity of *S. zeamais* treated with *S. africana* outer bark crude extracts at three different exposure times.

Anova for outer bark crude extracts treatment at 1 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	2830.000	3	943.333	3.065*
Error	11080.000	36	307.778	
Total	13910.000	39		

Anova for outer bark crude extracts treatment at 24 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	6190.000	3	2063.333	4.654*
Error	15960.000	36	443.333	
Total	22150.000	39		

Anova for outer bark crude extracts treatment at 48 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Treatments	6080.000	3	2026.667	3.619*
Error	20160.000	36	560.000	
Total	26240.000	39		

NS = Non-significant (P>0.05), * = Significant (P<0.05), ** = Highly Significant (P<0.01)

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Table 26. LSD post hoc multiple comparisons of mortality by contact toxicity caused by *S. africana* root crude extracts.

Time (h)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	24	-12.00*	2.909	.023	-19.42	-4.58
	48	-21.50*	2.909	.006	-28.92	-14.08
24	1	12.00*	2.909	.161	4.58	19.42
	48	-9.50*	2.909	.006	-16.92	-2.08
48	1	21.50*	2.909	.161	14.08	28.92
	24	9.50*	2.909	.023	2.08	16.92

* The mean difference is significant at the 0.05 level.

Table 27. LSD post hoc multiple comparisons of mortality by contact toxicity caused by *S. africana* outer bark extracts.

Time (h)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	24	-8.50*	1.939	.008	-13.45	-3.55
	48	-14.50*	1.939	.022	-19.45	-9.55
24	1	8.50*	1.939	.040	3.55	13.45
	48	-6.00*	1.939	.022	-10.95	-1.05
48	1	14.50*	1.939	.040	9.55	19.45
	24	6.00*	1.939	.008	1.05	10.95

* The mean difference is significant at the 0.05 level.

Table 28. Analysis of variance of repellent response caused by *S. africana* root crude extracts against *S. zeamais* at three different exposure periods.

Anova for root bark crude extracts treatment at 30 minutes exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Dosage	483.333	3	161.111	0.855*
Error	3766.667	20	188.333	
Total	4250	23		

Anova for root bark crude extracts treatment at 1 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Dosage	15.500	3	4.167	1.00*
Error	83.33	20	4.167	
Total	95.833	23		

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Anova for root bark crude extracts treatment at 4 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Dosage	483.333	3	161.111	0.25 NS
Error	12900	20	645	
Total	13383.333	23		

NS = Non-significant (P>0.05), * = Significant (P<0.05)

Table 29. Analysis of variance of repellent response caused by *S. africana* outer bark crude extracts against *S. zeamais* at three different exposure periods.

Anova for outer bark crude extracts treatment at 30 minutes exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Dosage	300	3	100	0.328 NS
Error	6100	20	305	
Total	6400	23		

Anova for outer bark crude extracts treatment at 1 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Dosage	1645.833	3	548.611	1.186*
Error	9250	20	462.5	
Total	10895.833	23		

Anova for outer bark crude extracts treatment at 4 hour exposure

Source of Variation	Sum of Squares	Df	Mean Square	F-value
Dosage	579.167	3	193.056	0.403 NS
Error	9583.333	20	479.167	
Total	10162.5	23		

NS = Non-significant (P>0.05),* = Significant (P<0.05)

Table 30. LSD post hoc multiple comparisons of repellent response caused by *S. africana* root crude extracts against *S. zeamais.*

Exposure Time		Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 h	30 min	.8350	3.77167	.973	-10.7375	12.4075
	4 h	7.9175	3.77167	.170	-3.6550	19.4900
30 min	1 h	-.8350	3.77167	.973	-12.4075	10.7375
	4 h	7.0825	3.77167	.225	-4.4900	18.6550
4 h	1 h	-7.9175	3.77167	.170	-19.4900	3.6550
	30 min	-7.0825	3.77167	.225	-18.6550	4.4900

*The mean difference is significant at the 0.05 level.

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Table 31. LSD post hoc multiple comparisons of repellent response caused by S. *africana* outer bark crude extracts against *S. zeamais*

Exposure Time		Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 h	30 min	.8350	3.77167	.973	-10.7375	12.4075
	4 h	7.9175	3.77167	.170	-3.6550	19.4900
30 min	1 h	-.8350	3.77167	.973	-12.4075	10.7375
	4 h	7.0825	3.77167	.225	-4.4900	18.6550
4 h	1 h	-7.9175	3.77167	.170	-19.4900	3.6550
	30 min	-7.0825	3.77167	.225	-18.6550	4.4900

*The mean difference is significant at the 0.05 level.

Table 32. Analysis of variance of maize grain undamaged treated with *S. africana* roots crude extracts

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	26.645	3	8.882	.475*
Error	224.348	12	18.696	
Total	250.993	15		

* = Highly Significant (P<0.01)

Table 33. Analysis of variance of maize grain undamaged treated with *S. africana* outer bark crude extracts

Source of Variation	Sum of Squares	df	Mean Square	F-value
Treatments	42.985	3	14.328	1.511*
Error	113.809	12	9.484	
Total	156.794	15		

* = Highly Significant (P<0.01)

Table 34. LSD post hoc multiple comparisons of *S. africana* root crude extracts dosage on undamaged maize grain

Dose (ml)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.5	1	2.24472	3.05742	.477	-4.4168	8.9063
	1.5	-1.36977	3.05742	.662	-8.0313	5.2918
	2	.33561	3.05742	.914	-6.3259	6.9972
1	0.5	-2.24472	3.05742	.477	-8.9063	4.4168
	1.5	-3.61449	3.05742	.260	-10.2760	3.0471
	2	-1.90912	3.05742	.544	-8.5707	4.7524
1.5	0.5	1.36977	3.05742	.662	-5.2918	8.0313
	1	3.61449	3.05742	.260	-3.0471	10.2760
	2	1.70538	3.05742	.587	-4.9562	8.3669
2	0.5	-.33561	3.05742	.914	-6.9972	6.3259
	1	1.90912	3.05742	.544	-4.7524	8.5707
	1.5	-1.70538	3.05742	.587	-8.3669	4.9562

*. The mean difference is significant at the 0.05 level.

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Table 35. LSD post hoc multiple comparisons of *S. africana* outer bark crude extracts dosage on undamaged maize grain

Dose (ml)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.5	1	-1.25106	2.17763	.576	-5.9957	3.4936
	1.5	2.71591	2.17763	.236	-2.0287	7.4606
	2	2.32133	2.17763	.307	-2.4233	7.0660
1	0.5	1.25106	2.17763	.576	-3.4936	5.9957
	1.5	3.96698	2.17763	.094	-.7777	8.7116
	2	3.57240	2.17763	.127	-1.1722	8.3170
1.5	0.5	-2.71591	2.17763	.236	-7.4606	2.0287
	1	-3.96698	2.17763	.094	-8.7116	.7777
	2	-.39458	2.17763	.859	-5.1392	4.3501
2	0.5	-2.32133	2.17763	.307	-7.0660	2.4233
	1	-3.57240	2.17763	.127	-8.3170	1.1722
	1.5	.39458	2.17763	.859	-4.3501	5.1392

*. The mean difference is significant at the 0.05 level.

Table 36. Analysis of variance of feeding deterrent by weight loss of maize grain treated with *S. africana* root crude extracts

Source of Variation	Sum of Squares	df	Mean Square	F
Dosage	263.441	4	65.86	14.139**
Error	69.871	15	4.658	
Total	333.312	19		

** = Highly Significant (P<0.01)

Table 37. Analysis of variance of feeding deterrent by weight loss of maize grain treated with *S. africana* outer bark crude extracts

Source of Variation	Sum of Squares	df	Mean Square	F
Dosage	248.333	4	62.083	13.516**
Error	68.899	15	4.593	
Total	317.232	19		

** = Highly Significant (P<0.01)

Table 38. LSD post hoc multiple comparisons of *S. africana* root crude extracts dosage on maize grain weight loss

Dose of Root Crude extracts (ml)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.5	1	.0800	.15876	.956	-.4156	.5756
	1.5	-.5850*	.15876	.022	-1.0806	-.0894

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	2	.4150	.15876	.107	-.0806	.9106
1	0.5	-.0800	.15876	.956	-.5756	.4156
	1.5	-.6650*	.15876	.010	-1.1606	-.1694
	2	.3350	.15876	.221	-.1606	.8306
1.5	0.5	.5850*	.15876	.022	.0894	1.0806
	1	.6650*	.15876	.010	.1694	1.1606
	2	1.0000*	.15876	.001	.5044	1.4956
2	0.5	-.4150	.15876	.107	-.9106	.0806
	1	-.3350	.15876	.221	-.8306	.1606
	1.5	-1.0000*	.15876	.001	-1.4956	-.5044

*. The mean difference is significant at the 0.05 level.

Table 39. LSD post hoc multiple comparisons of *S. africana* outer bark crude extracts dosage on maize grain weight loss

Dose of Outer bark crude extracts (ml)		Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.5	1	.0825	.13813	.930	-.3487	.5137
	1.5	.0825	.13813	.930	-.3487	.5137
	2	.1675	.13813	.635	-.2637	.5987
1	0.5	-.0825	.13813	.930	-.5137	.3487
	1.5	.0000	.13813	1.000	-.4312	.4312
	2	.0850	.13813	.925	-.3462	.5162
1.5	0.5	-.0825	.13813	.930	-.5137	.3487
	1	.0000	.13813	1.000	-.4312	.4312
	2	.0850	.13813	.925	-.3462	.5162
2	0.5	-.1675	.13813	.635	-.5987	.2637
	1	-.0850	.13813	.925	-.5162	.3462
	1.5	-.0850	.13813	.925	-.5162	.3462

*. The mean difference is significant at the 0.05 level.

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Table 39. LSD post hoc multiple comparisons of *S. africana* outer bark crude extracts dosage on maize grain weight loss

Dose of Outer bark crude extracts (ml)		Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.5	1	.0825	.13813	.930	-.3487	.5137
	1.5	.0825	.13813	.930	-.3487	.5137
	2	.1675	.13813	.635	-.2637	.5987
1	0.5	-.0825	.13813	.930	-.5137	.3487
	1.5	.0000	.13813	1.000	-.4312	.4312
	2	.0850	.13813	.925	-.3462	.5162
1.5	0.5	-.0825	.13813	.930	-.5137	.3487
	1	.0000	.13813	1.000	-.4312	.4312
	2	.0850	.13813	.925	-.3462	.5162
2	0.5	-.1675	.13813	.635	-.5987	.2637
	1	-.0850	.13813	.925	-.5162	.3462
	1.5	-.0850	.13813	.925	-.5162	.3462

*. The mean difference is significant at the 0.05 level

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Appendix VII: Raw data of effect of *S. africana* powder against *S. zeamais* at 30, 60 and 90 days post treatment

Table 40. Raw data on toxicity of *S. africana* powder against *S. zeamais* at different dosages at 30 days post treatment

Leaves	Dose (g)	Mortality (%)	Dose (g)	Mortality (%)	Dose (g)	Mortality (%)	Dose (g)	Mortality (%)
	5	10	2.5	25	0.5	0	0.05	5
	5	0	2.5	5	0.5	20	0.05	30
	5	40	2.5	90	0.5	30	0.05	25
	5	45	2.5	80	0.5	65	0.05	85
	Average	23.75		50		28.75		36.25
Seeds	5	70	2.5	45	0.5	15	0.05	10
	5	10	2.5	10	0.5	35	0.05	0
	5	10	2.5	85	0.5	25	0.05	30
	5	35	2.5	30	0.5	35	0.05	15
	Average	31.25		42.5		27.5		13.75
Roots	5	85	2.5	90	0.5	35	0.05	70
	5	95	2.5	90	0.5	85	0.05	55
	5	100	2.5	95	0.5	40	0.05	45
	5	90	2.5	95	0.5	80	0.05	85
	Average	92.5		92.5		60		63.75
Bark outer	5	60	2.5	5	0.5	15	0.05	5
	5	75	2.5	40	0.5	15	0.05	30
	5	90	2.5	75	0.5	85	0.05	65
	5	60	2.5	50	0.5	40	0.05	30

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	Average	71.25		42.5		38.75		32.5
Inner bark	**5**	0	**2.5**	5	**0.5**	5	**0.05**	5
	5	5	**2.5**	15	**0.5**	10	**0.05**	15
	5	10	**2.5**	5	**0.5**	0	**0.05**	0
	5	30	**2.5**	5	**0.5**	5	**0.05**	5
	Average	11.25		7.5		5		6.25
Control	**0**	0						
	0	5						
	0	10						
	0	5						
	0	0						
	Average	4						

Table 41. Raw data of toxicity of *S. africana* against *S. zeamais* at different dosages at 60 days post treatment

Leaves	**Dose (g)**	Mortality (%)	**Dose (g)**	Mortality (%)	**Dose (g)**	Mortality (%)	**Dose (g)**	Mortality (%)
	5	50	**2.5**	40	**0.5**	60	**0.05**	60
	5	60	**2.5**	42.5	**0.5**	53	**0.05**	45
	5	65.2	**2.5**	42	**0.5**	35	**0.05**	60
	5	100	**2.5**	100	**0.5**	100	**0.05**	100
	Average	68.8		56.125		62		66.25
Seeds								
	5	48	**2.5**	58	**0.5**	66	**0.05**	55
	5	45.3	**2.5**	40	**0.5**	60	**0.05**	63

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	5	35.2	2.5	63.2	0.5	85	0.05	90
	5	100	2.5	100	0.5	100	0.05	100
	Average	57.125		65.3		77.75		77
Roots	5	50	2.5	35.2	0.5	45	0.05	35
	5	46	2.5	49	0.5	77	0.05	46.3
	5	5.3	2.5	53	0.5	43.2	0.05	50.6
	5	100	2.5	100	0.5	100	0.05	100
	Average	50.325		59.3		66.3		57.975
Bark outer	5	48.3	2.5	50.3	0.5	50	0.05	56
	5	45.2	2.5	44.3	0.5	45	0.05	43
	5	43.3	2.5	48.3	0.5	43.2	0.05	43.3
	5	100	2.5	100	0.5	100	0.05	100
	Average	59.2		60.725		59.55		60.575
Inner bark	5	45.3	2.5	38.1	0.5	60	0.05	40.3
	5	40	2.5	50	0.5	35.2	0.05	61.3
	5	60	2.5	45.9	0.5	40	0.05	60
	5	100	2.5	100	0.5	100	0.05	100
		61.325		58.5		58.8		65.4
Control	0	43						
	0	50						
	0	23						
	0	43						
	0	60						
	Average	43.8						

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Table 42. Raw data of toxicity of *S. africana* against *S. zeamais* at different dosages at 90 days post treatment

Leaves	**Dose (g)**	Mortality (%)	**Dose (g)**	Mortality (%)	**Dose (g)**	Mortality (%)	**Dose (g)**	Mortality (%)
	5	96	**2.5**	80.4	**0.5**	95.8	**0.05**	93.79
	5	94.6	**2.5**	95.5	**0.5**	83.32	**0.05**	16
	5	89.52	**2.5**	89.04	**0.5**	78.95	**0.05**	88.9
	5	100	**2.5**	100	**0.5**	100	**0.05**	100
	Average	95.03		91.235		89.5175		74.673
Seeds								
	5	97.59	**2.5**	99	**0.5**	77	**0.05**	98.24
	5	92.86	**2.5**	86.55	**0.5**	90.78	**0.05**	85.47
	5	63.92	**2.5**	94.06	**0.5**	80	**0.05**	77.46
	5	100	**2.5**	100	**0.5**	100	**0.05**	100
	Average	88.5925		94.9025		86.945		90.293
Roots	**5**	100	**2.5**	77.27	**0.5**	93.75	**0.05**	87.87
	5	100	**2.5**	86.36	**0.5**	89.36	**0.05**	93.7
	5	100	**2.5**	92.85	**0.5**	84.54	**0.05**	90.27
	5	100	**2.5**	100	**0.5**	100	**0.05**	100
	Average	100		89.12		91.9125		92.96
Bark outer	**5**	90.48	**2.5**	96.29	**0.5**	100	**0.05**	98.52
	5	91.47	**2.5**	90.49	**0.5**	90.49	**0.05**	95.68
	5	95.77	**2.5**	99.12	**0.5**	96.42	**0.05**	91.93
	5	100	**2.5**	100	**0.5**	100	**0.05**	100
	Average	94.43		96.475		96.7275		96.533

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Inner bark	5	96.91	2.5	94.73	0.5	72.87	0.05	76.34
	5	96.39	2.5	82.05	0.5	92.42	0.05	81.42
	5	95.33	2.5	94.02	0.5	97.72	0.05	92.02
	5	100	2.5	100	0.5	100	0.05	100
	Average	97.1575		92.7		90.7525		87.445
Control	0	85.32						
	0	49.21						
	0	81.34						
	0	74.64						
	0	43.5						
	Average	66.802						

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Table 43. Raw data on maize grain weight loss caused by *S. zeamais* at 30 days post treatment

Leaves	Dose (g)	Weight loss (%)	Dose (g)	Weight loss (%)	Dose (g)	Weight loss (%)	Dose (g)	Weight loss (%)
	5	2	2.5	3	0.5	3	0.05	0
	5	1	2.5	1	0.5	3	0.05	2
	5	2	2.5	3	0.5	7	0.05	4
	5	4	2.5	3	0.5	3	0.05	3
	Average	2.25		2.5		4		2.25
Seeds	5	0	2.5	0	0.5	0	0.05	0
	5	0	2.5	0	0.5	0	0.05	0
	5	3	2.5	4	0.5	6	0.05	8
	5	5	2.5	6	0.5	4	0.05	5
	Average	2		2.5		2.5		3.25
Roots	5	0	2.5	0	0.5	0	0.05	0
	5	0	2.5	0	0.5	0	0.05	0
	5	0	2.5	0	0.5	0	0.05	0
	5	6	2.5	12	0.5	7	0.05	3
	Average	1.5		3		1.75		0.75
Bark outer	5	0	2.5	8	0.5	6	0.05	14
	5	1	2.5	3	0.5	4	0.05	3
	5	4	2.5	4	0.5	3	0.05	6
	5	4	2.5	4	0.5	6	0.05	4
	Average	2.25		4.75		4.75		6.75
Inner bark	5	0	2.5	0	0.5	0	0.05	0

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	5	0	**2.5**	0	**0.5**	0	**0.05**	0
	5	0	**2.5**	0	**0.5**	0	**0.05**	0
	5	4	**2.5**	0	**0.5**	0	**0.05**	3
	Average	1		0		0		0.75
Control	**0**	14						
	0	12						
	0	16						
	0	13						
	0	15						
	Average	14						

Table 44. Raw data on maize grain weight loss caused by *S. zeamais* at 60 days post treatment

Leaves	**Dose (g)**	Weight loss (%)	**Dose (g)**	Weight loss (%)	**Dose (g)**	Weight loss (%)	**Dose (g)**	Weight loss (%)
	5	13	**2.5**	26	**0.5**	24	**0.05**	21
	5	12	**2.5**	24	**0.5**	26	**0.05**	22
	5	11	**2.5**	27	**0.5**	22	**0.05**	24
	5	14	**2.5**	25	**0.5**	24	**0.05**	16
	Average	12.5		25.5		24		20.75
Seeds								
	5	15	**2.5**	16	**0.5**	18	**0.05**	22
	5	17.8	**2.5**	18.2	**0.5**	24	**0.05**	25
	5	16.1	**2.5**	20	**0.5**	19	**0.05**	20
	5	14.3	**2.5**	19	**0.5**	22	**0.05**	19

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	Average	15.8		18.3		20.75		21.5
Roots	**5**	3.3	**2.5**	9	**0.5**	14	**0.05**	15
	5	2.6	**2.5**	10	**0.5**	8	**0.05**	14
	5	3	**2.5**	11	**0.5**	11	**0.05**	13
	5	2	**2.5**	7	**0.5**	13	**0.05**	17
	Average	2.725		9.25		11.5		14.75
Bark outer	**5**	4	**2.5**	11	**0.5**	13.2	**0.05**	15.2
	5	3.1	**2.5**	10	**0.5**	11.2	**0.05**	14.1
	5	3.2	**2.5**	9	**0.5**	12.8	**0.05**	13
	5	2.6	**2.5**	12.1	**0.5**	9.8	**0.05**	16.8
	Average	3.225		10.525		11.75		14.775
Inner bark	**5**	13	**2.5**	15.2	**0.5**	16.3	**0.05**	17.2
	5	10	**2.5**	14	**0.5**	15	**0.05**	16.3
	5	13	**2.5**	12	**0.5**	14.7	**0.05**	12.7
	5	16	**2.5**	19.8	**0.5**	19	**0.05**	19.8
	Average	13		15.25		16.25		16.5
Control	**0**	29.3						
	0	30						
	0	33						
	0	28						
	0	37.4						
	Average	31.54						

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Table 45. Raw data on maize grain weight loss caused by *S. zeamais* at 90 days post treatment

Leaves	**Dose (g)**	Weight loss (%)	**Dose (g)**	Weight loss (%)	**Dose (g)**	Weight loss (%)	**Dose (g)**	Weight loss (%)
	5	24	**2.5**	36	**0.5**	44	**0.05**	40
	5	14	**2.5**	12	**0.5**	6	**0.05**	12
	5	38	**2.5**	34	**0.5**	36	**0.05**	38
	5	28	**2.5**	22	**0.5**	14	**0.05**	8
	Average	26		26		25		24.5
Seeds								
	5	38	**2.5**	45	**0.5**	35	**0.05**	42
	5	18	**2.5**	24	**0.5**	18	**0.05**	14
	5	30	**2.5**	34	**0.5**	40	**0.05**	46
	5	16	**2.5**	30	**0.5**	20	**0.05**	14
	Average	25.5		33.25		28.25		29
Roots	**5**	4	**2.5**	20	**0.5**	24	**0.05**	50
	5	10	**2.5**	14	**0.5**	18	**0.05**	18
	5	8	**2.5**	12	**0.5**	14	**0.05**	30
	5	4	**2.5**	12	**0.5**	2	**0.05**	8
	Average	6.5		14.5		14.5		26.5
Bark outer	**5**	8	**2.5**	24	**0.5**	24	**0.05**	36
	5	11	**2.5**	12	**0.5**	14	**0.05**	12
	5	12	**2.5**	36	**0.5**	44	**0.05**	48
	5	8	**2.5**	12	**0.5**	6	**0.05**	10

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	Average	9.75		21		22		26.5
Inner bark	**5**	48	**2.5**	50	**0.5**	50	**0.05**	50
	5	24	**2.5**	20	**0.5**	22	**0.05**	24
	5	38	**2.5**	38	**0.5**	50	**0.05**	36
	5	52	**2.5**	38	**0.5**	44	**0.05**	40
	Average	40.5		36.5		41.5		37.5
Control	**0**	49						
	0	46.6						
	0	49.3						
	0	48						
	0	47.6						
	Average	48.1						

Table 46. Raw Data of *S. zeamais* adult emergency at 60 days post treatment

Leaves	**Dose (g)**	Adult emergence	**Dose (g)**	Adult emergence	**Dose (g)**	Adult emergence	**Dose (g)**	Adult emergence
	5	23.2	**2.5**	32.3	**0.5**	33.1	**0.05**	30.3
	5	20	**2.5**	29	**0.5**	31.3	**0.05**	31.3
	5	19.1	**2.5**	28.1	**0.5**	32.3	**0.05**	29.4
	5	23.4	**2.5**	30.2	**0.5**	30.3	**0.05**	28.1
	Average	21.425		29.9		31.75		29.775
Seeds	**5**	31.1	**2.5**	34.3	**0.5**	33.2	**0.05**	34.3
	5	29.2	**2.5**	35.1	**0.5**	32.1	**0.05**	25.2
	5	33	**2.5**	36	**0.5**	35	**0.05**	29.3

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	5	24.3	2.5	35.2	0.5	28	0.05	31.1
	Average	29.4		35.15		32.075		29.975
Roots	5	12.2	2.5	18.6	0.5	21.2	0.05	25.2
	5	10	2.5	23.1	0.5	20	0.05	28
	5	14	2.5	17	0.5	19	0.05	19.1
	5	9	2.5	16	0.5	23	0.05	23
	Average	11.3		18.675		20.8		23.825
Bark outer	5	16.2	2.5	23.2	0.5	20.4	0.05	25.4
	5	15.1	2.5	22.1	0.5	22	0.05	24
	5	14	2.5	24.5	0.5	21.4	0.05	26.3
	5	14.7	2.5	18.2	0.5	18.1	0.05	23.3
	Average	15		22		20.475		24.75
Inner bark	5	23.4	2.5	25.3	0.5	27.3	0.05	28.2
	5	20	2.5	24	0.5	26.2	0.05	28
	5	26	2.5	26	0.5	25.8	0.05	27
	5	19.6	2.5	24	0.5	26.7	0.05	26
	Average	22.25		24.825		26.5		27.3
Control	0	42.5						
	0	50						
	0	43						
	0	40						
	0	53.4						
	Average	45.78						

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Table 47. Raw Data of *S. zeamais* adult emergency at 90 days post treatment

Leaves	Dose (g)	Adult emergence	Dose (g)	Adult emergence	Dose (g)	Adult emergence	Dose (g)	Adult emergence
	5	82	2.5	83	0.5	90	0.05	91
	5	71	2.5	69	0.5	39	0.05	50
	5	90	2.5	82	0.5	85	0.05	20
	5	83	2.5	84	0.5	65	0.05	57
	Average	81.5		79.5		69.75		54.5
Seeds								
	5	89	2.5	91	0.5	89	0.05	91
	5	80	2.5	87	0.5	84	0.05	72
	5	84	2.5	79	0.5	87	0.05	91
	5	67	2.5	88	0.5	89	0.05	79
	Average	80		86.25		87.25		83.25
Roots	5	47	2.5	76	0.5	82	0.05	89
	5	76	2.5	64	0.5	77	0.05	87
	5	66	2.5	77	0.5	57	0.05	84
	5	82	2.5	67	0.5	5	0.05	67
	Average	67.75		71		55.25		81.75
Bark outer	5	72	2.5	82	0.5	76	0.05	84
	5	80	2.5	81	0.5	71	0.05	66
	5	84	2.5	86	0.5	92	0.05	93

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	5	52	2.5	71	0.5	5	0.05	26
	Average	72		80		61		67.25
Inner bark	5	92	2.5	91	0.5	94	0.05	94
	5	88	2.5	83	0.5	81	0.05	86
	5	90	2.5	87	0.5	92	0.05	89
	5	91	2.5	90	0.5	89	0.05	89
	Average	90.25		87.75		89		89.5
Control	0	97						
	0	98						
	0	96						
	0	98						
	0	95						
	Average	96.8						

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Appendix VIII: Raw data of laboratory bioassay of *S. africana* root and outer bark crude extracts against *S. zeamais*.

Table 48. Raw data of repellency response caused by root crude extracts

Root	30 min	1h	4h
Experiment 1	90	90	100
	100	100	100
	100	100	100
	80	100	60
	70	100	50
	70	100	100
Average	**85**	**98.3333**	**85**
Experiment 2	100	100	100
	100	100	100
	100	100	100
	70	100	30
	100	100	100
	100	100	30
Average	**95**	**100**	**76.6667**
Experiment 3	90	100	100
	100	100	100
	100	100	100
	60	100	100
	80	100	70
	90	100	60
Average	**86.6667**	**100**	**88.3333**
Experiment 4	100	100	90
	90	100	100
	90	100	100

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	80	100	80
	60	100	50
	80	100	100
Average	**83.3333**	**100**	**86.6667**
Overall mean	87.5	99.5833	84.1667

Table 49. Raw data of repellency response caused by outer bark crude extracts

Outer bark	**30 min**	**1h**	**4h**
Experiment 1	90	90	70
	100	100	100
	100	100	100
	50	80	70
	60	90	90
	80	70	60
Average	**80**	**88.3333**	**81.6667**
Experiment 2	100	100	100
	100	100	100
	100	90	100
	60	70	80
	80	80	80
	60	80	70
Average	**83.3333**	**86.6667**	**88.3333**
Experiment 3	90	100	10
	100	100	100
	100	100	100
	60	100	80
	90	90	70
	90	60	60
Average	**88.3333**	**91.6667**	**70**

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Experiment 4	100	10	100
	100	100	90
	100	100	100
	80	100	60
	80	100	100
	70	60	100
Average	**88.3333**	**78.3333**	**91.6667**
Overall mean	85	86.25	82.9167

Table 50. Raw data of contact toxicity caused by root crude extracts

Root	1 h	24 h	48 h
Experiment 1	0	0	20
	20	40	60
	20	60	80
	0	20	60
	20	60	60
	40	40	60
	20	40	40
	20	40	40
	20	20	60
	20	60	80
Average	**18**	**38**	**56**
Experiment 2	20	40	60
	0	20	40
	0	0	0
	0	20	40
	20	40	60
	0	0	0
	0	20	0
	0	0	20
	0	40	60

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	20	20	40
Average	**6**	**20**	**32**
Experiment 3	0	20	20
	20	20	20
	0	0	20
	0	0	40
	20	0	40
	0	40	0
	0	0	0
	60	0	0
	0	20	20
	0	0	0
Average	**10**	**10**	**16**
Experiment 4	20	20	20
	20	20	20
	0	20	20
	60	60	60
	60	100	100
	40	80	80
	20	20	20
	0	40	40
	0	0	20
	0	0	0
Average	**22**	**36**	**38**
Overall mean	14	26	35,5

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Table 51. Raw data of contact toxicity caused outer bark crude extracts

Outer bark	1 h	24 h	48 h
Experiment 1	20	20	0
	0	0	40
	0	0	20
	0	0	0
	20	0	0
	0	0	20
	0	0	0
	0	0	20
	0	0	0
	0	40	20
Average	**4**	**6**	**12**
Experiment 2	20	20	40
	0	20	20
	0	40	40
	0	20	20
	40	40	60
	40	40	40
	40	40	40
	40	40	40
	40	60	80
	20	20	20
Average	**24**	**34**	**40**
Experiment 3	40	60	80
	20	40	60
	0	20	20
	40	40	60
	20	40	40

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	20	40	40
	40	40	40
	40	40	40
	20	20	40
	0	0	20
Average	**24**	**34**	**44**
Experiment 4	20	20	0
	20	20	0
	0	20	0
	60	60	60
	60	100	100
	40	80	80
	20	20	20
	0	40	40
	0	0	20
	0	0	0
Average	**22**	**36**	**32**
Overall mean	18,5	27.5	32

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Table 52. Raw data of undamaged grain treated with *S. africana* crude extracts

S. africana crude extracts	**Dose (ml)**	Undamaged grains (%)	**Dose (ml)**	Undamaged grains (%)	**Dose (ml)**	Undamaged grains (%)	**Dose (ml)**	Undamaged grains (%)
Root	**0.5**	80,4196	**1**	80,5085	**1.5**	81,7518	**2**	75,2137
	0.5	84,2466	**1**	77,6316	**1.5**	86,8966	**2**	84,1379
	0.5	80	**1**	77,92208	**1.5**	74,17219	**2**	79,72973
	0.5	81,81818	**1**	81,4433	**1.5**	89,14286	**2**	86,06061
	Average	**81,6211**		79,3764		82,9909		**81,2855**
Outer bark	**0.5**	83,9695	**1**	81,6327	**1.5**	78,8462	**2**	77,4775
	0.5	82,069	**1**	83,9161	**1.5**	85,2713	**2**	81,9444
	0.5	83,00654	**1**	89,79592	**1.5**	78,61635	**2**	86,27451
	0.5	85,80247	**1**	84,50704	**1.5**	81,25	**2**	79,86577
	Average	**83,7119**		**84,9629**		80,996		81,3906
Control	**0**	78,66599						
	0	77,16501						
	0	74,30928						
	0	75,5383						
	Average	76,41964						

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Table 53. Raw data of feeding deterrent by maize grain damage treated with *S. africana* crude extracts.

S. africana crude extracts	**Dose (ml)**	Damaged grains (%)	**Dose (ml)**	Damaged grains (%)	**Dose (ml)**	Damaged grains (%)	**Dose (ml)**	Damaged grains (%)
Root	**0.5**	20	**1**	16,4286	**1.5**	17,8571	**2**	20,7143
	0.5	16,4286	**1**	24,2857	**1.5**	13,5714	**2**	16,4286
	0.5	20	**1**	22,07792	**1.5**	25,82781	**2**	20,27027
	0.5	18,18182	**1**	18,5567	**1.5**	10,85714	**2**	13,93939
	Average	**18,6526**		**20,3571**		**15,7143**		**18,5714**
Outer bark	**0.5**	15	**1**	12,8571	**1.5**	23,5714	**2**	17,8571
	0.5	18,5714	**1**	16,4286	**1.5**	13,5714	**2**	18,5714
	0.5	16,99346	**1**	10,20408	**1.5**	21,38365	**2**	13,72549
	0.5	14,19753	**1**	15,49296	**1.5**	18,75	**2**	20,13423
	Average	16,1906		14,6429		18,5714		18,2143
Control	**0**	24,29						
	0	22.14						
	0	26.79						
	0	21.07						
	Average	23.57						

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Table 54. Raw data of feeding deterrent by maize grain weight loss treated with *S. africana* crude extracts.

S. africana crude extracts	**Dose (ml)**	Weight loss (%)	**Dose (ml)**	Weight loss (%)	**Dose (ml)**	Weight loss (%)	**Dose (ml)**	Weight loss (%)
Root	**0.5**	4.6667	**1**	4.6667	**1.5**	5.3333	**2**	4.6667
	0.5	9.3333	**1**	9.3333	**1.5**	9.6667	**2**	9
	0.5	9.3333	**1**	9	**1.5**	10	**2**	8.3333
	0.5	9.3333	**1**	9.3333	**1.5**	10	**2**	9
	Average	8.1667		8.0833		8.75		7.75
Outer bark	**0.5**	5.3333	**1**	5	**1.5**	5	**2**	5
	0.5	9.6667	**1**	9.6667	**1.5**	9.3333	**2**	9.3333
	0.5	9.3333	**1**	9.6667	**1.5**	9.6667	**2**	9.6667
	0.5	9.6667	**1**	9.3333	**1.5**	9.6667	**2**	9.3333
	Average	8.5		8.4167		8.4167		8.3333
Control	**0**	16.2						
	0	15.3						
	0	19						
	0	18.4						
	Average	17.225						

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