BIOECOLOGY AND MANAGEMENT OF COFFEE BEAN WEEVIL, (*Araecerus fasciculatus* De Geer) ON SOME STORED FOOD CROPS IN SELECTED STATES IN NIGERIA

By

Felicia Abosede GBOLAHAN
B. Tech. (Ogbomoso), M.Sc. (Ibadan)
Matric No.: 142818

A Thesis in the Department of Crop Protection and Environmental Biology Submitted to the Faculty of Agriculture
In partial fulfillment of the requirements of the Degree of

DOCTOR OF PHILOSOPHY

of the

UNIVERSITY OF IBADAN

SEPTEMBER 2021

CERTIFICATION

I certify that this work was carried out by Felicia Abosede GBOLAHAN in the Department of Crop Protection and Environmental Biology, Faculty of Agriculture, University of Ibadan, Ibadan Nigeria

---

(Supervisor)

Professor A. A. OMOLOYE

Entomologist/ Applied Ecologist

B. Sc. Ed. (Benin), M. Sc., Ph.D. (Ibadan), FESN, FHNR, JP

Professor, Department of Crop Protection and Environmental Biology,

University of Ibadan, Nigeria

DEDICATION

This work is dedicated to Lord God Almighty for His mercy and grace. Also, to my lovely husband, Mr Olawale Gbolahan and my blessed children, Juwon, Jubel and Gold for their support and understanding during the period of this study.

ACKNOWLEDGEMENTS

I appreciate my supervisor, Professor A. A. Omoloye for his outstanding academic support and immeasurable guidance and patience which helped in the successful completion of this study. You are a father in need and indeed. I appreciate the constructive criticism, time and support of my supervisory committee; Dr O.Y. Alabi, Dr. O.S. Olubode, Dr Akinbuluma, Dr Osunsanya, Dr Dada. I appreciate my academic mentor, Prof. F.K. Ewete for his academic support and helpful discussions on this research work.

I acknowledge the Head, Prof. R. O. Awodoyin and staff of the Department of Crop Protection and Environmental Biology (CPEB), University of Ibadan for their support and provision of an enabling environment. I appreciate all post graduate students of Department of CPEB for their moral support. My special thanks go to the management of Federal College of Land Resources (FECOLART), Owerri for the travelling opportunities given to me to pursue this study. I am extremely grateful to Dr. James Ojo, Dr. Samuel Babarinde and Mr. Okeke Sidney for their moral support and helpful discussions.

I appreciate the friendship and moral support of my childhood friends Adeyokun Adeboyejo, Gabriel Olajiire, Osunpidan Olukunle, Ogunsola Folashade, Adeyemi Oyindamola, Hassan Mohammed, Kehinde Opabiyi. Special thanks to my Mummy, Mrs Sarah Iyiola for taking care of my children during the course of this study. To my siblings, Pastor and Mrs. Ojo Oyebami, Mr. and Mrs. Adedeji, Mr. and Mrs. Akintunde Iyiola, Mr. and Mrs. Segun Sonibare, my niece, Kemi Ogundiran, Sharon Ojo, my nephew Sunday Adedeji for their prayers and support. Big thanks to everyone who has provided moral support, prayers and friendship, I appreciate you all.

Special appreciation goes to my caring and loving husdand, Olawale Gbolahan for his support, endurance and love, to my children, Sharon, Juwon, Jubel and Gold for their support, bearing and sharing the pain and burden to see that mummy acquired a higher degree, you deserve an accolade. I am grateful to God Almighty for His unfailing love throughout this journey. To God be the glory.

ABSTRACT

Stored Food Crops (SFC) serve as host to Insect Pests (IP). *Araecerus fasciculatus* (Af) is a major IP causing severe economic losses in Nigeria. In a bid to prevent deterioration on Food Crops (FC), farmers process FC into Dried Chips (DC), nonetheless, the DC are susceptible to Af damage. Use of synthetic insecticides to reduce activity of Af is a common practice but with attendant environmental hazards. Knowledge of Af Life Stages (LS) and its relationship with other IP on SFC are required for safe and effective control, however, specific information on its biology and safe management are scanty. Thus, the bioecology and management of Af on DC of selected SFC were investigated.

Dried Chips (5kg each) of cassava, potato, Water Yam (WaY), White Yam (WhY) and plantain were collected in different markets in Osun, Oyo, Ondo, Kwara and Ekiti states where SFC were predominant to assess occurrence and abundance of IP using standard procedures. The LS of Af on different DC was assessed using standard procedures. Developmental Period (DP, days), Number of Eggs Laid (NEL), Adult Longevity (AL, days), morphometrics of adults (mm) were recorded. Management of Af on DC by blanching with mixture of fermented maize water (mL), water (mL) and lime (mL) in varying concentrations to obtain, T_1 (250.0+747.5+2.5), T_2 (250.0+745.0+5.0), T_3 (250.0+742.5+7.5), T_4 (250.0+740.0+10.0); controls comprised T_5 (250.0+750.0+0.0) and T_6 (0.0+1000.0+0.0), respectively were laid out in complete randomised design (r=4). The AL, DP and WL (g) of DC were determined using standard methods. Diversity of emerged IP was assessed using Shannon-Wiener (H`, low=0-0.9; high=1-4.6) and evenness indices (low=0; high=1). Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.

Araecerus fasciculatus (93.22±3.14), *Dinoderus minutus* (74.89±1.62) and *Prostephanus truncatus,* (71.33±1.42), occurred as most abundant IP on DC across states. *Araecerus fasciculatus* had seven life-stages: egg, four larva-instars, pupa and adult. The DP of Af on plantain, potato, cassava, WhY and WaY were 42.25±1.44, 45.50±2.06, 47.00±0.91, 49.75±0.91 and 52.75±2.87, respectively. The NEL by Af was in order 100.00±3.24 (WhY) > 94.00±4.42 (WaY) > 62.00±4.05 (cassava) > 58.00±4.05 (plantain) and > 53.00±7.46 (potato). The AL on DC were 105.0 (WaY), 99.5 (WhY), 91.5 (Potato), 88.5 (cassava) and 66.5 (plantain). Male length and width were 2.74-3.89 and 1.06-1.28, while female length and width were 3.82-3.88 and 1.76-1.86. The AL (105.00±3.87) of WaY treated with T_5 was significantly longer (31.75±1.18) than cassava treated with T_4. The DP was longest (78.25±0.85) on WhY treated with T_4 and significantly higher (42.25±1.93) than cassava treated with T_5. The plantain DC treated with T_5 had highest WL (37.13±1.10) and was significantly higher (0.34±0.10) than potato DC treated with T_4. The H` and evenness indices ranged from 0.00-2.01 and 0.63-1.00, respectively.

Araecerus fasciculatus was the major insect pest of dried chips in Nigeria with developmental period spanning 42 to 52 days. Blanching with mixture of 740 mL water with 250 mL fermented maize water and 10 mL lime protected dried chips and can be utilized for an effective management of *Araecerus fasciculatus*.

Keywords: *Araecerus fasciculatus,* Coffee bean weevil life stages, Fermented maize water

Word count: 496

TABLE OF CONTENTS

	Title	i
	Certification	ii
	Dedication	iii
	Acknowledgement	iv
	Abstract	v
	Table of Contents	vi
	List of Tables	x
	List of Figures	xiii
	List of Plates	ix
	CHAPTER ONE	1
	Introduction	1
	CHAPTER TWO	5
	Literature Review	5
2.1	Insect pests associated with root and tuber chips	5
2.2	History and Significance of *Araecerus fasciculatus* De Geer	6
2.3	Biology of A. *fasciculatus* De Geer	6
2.4	Distribution and economic importance of *Araecerus fasciculatus* DeGeer	8
2.5	Taxonomy of the Coffee bean weevil: *Araecerus fasciculatus* De Geer	9
2.6	Occurrence of *A. fasciculatus* on Crops and Plant Products	10
2.7	*Araecerus fasciculatus* as a Storage Pest	10
2.8	Control Measures taken Against *A. fasciculatus*	11
2.9	Yam *(Dioscorea* spp) (Origin, Production, Utilization)	12
2.10	Constraints to Yam Production	13
2.11	Methods of Yam Processing	14
2.12	Origin, Utilization and Production of Cassava	14
2.13	Constraints to Cassava Production	16
2.14	Methods of Processing Dried Cassava Chips	16
2.15	Origin, Utilization and Production of Sweet Potato	18
2.16	Methods of Processing Sweet Potato	19

2.17	Origin and Production of Plantain	20
2.18	Methods of Processing Plantain	21
2.19	Organochlorine Pesticides	22
2.20	Insects Pest of Dried Chips	22
2.21	Control of Insect Pest of Dried chips	23
2.22	Role of phytochemical in Insect Control	23
	CHAPTER THREE	25
	Materials and Methods	25
3.1	The Study Sites	25
3.2	Sample collection and culture establishment	25
3.3	Survey and assessment of the abundance and diversity of insect species associated with the food hosts in selected locations	27
3.4	Determine the Organochlorine contamination of dried cassava and yam chips in selected locations in Nigeria	28
3.4.1	Sample Extraction	28
3.4.2	Chromatographic Column Clean up	28
3.5	Comparative Biology *of Araecerus fasciculatus* on Selected Dried Chips	29
3.5.1	Preparation of dried chips	29
3.5.2	Life stages of *A. fasciculatus* on selected dry chips.	29
3.5.3	Determination of Host Preference of of *Araecerus fasciculatus*	32
3.5.3.1	Preference and fertility study of *Araecerus fasciculatus* using free choice method	33
3.5.3.2	Non-preference and fertility study of *Araecerus fasciculatus*	33
3.6	Assessment of qualitative and quantitative damage by *Araecerus fasciculatus* on selected dried chips.	34
3.7	Analysis of infested and non-infested samples for proximate and mineral analysis	35
3.7.1	Determination of Crude Protein (AOAC Official Method 2005)	35
3.7.2	Crude Fat Determination	36
3.7.3	Dry Matter and Moisture Determination	37
3.7.4	Determination of Ash	37

3.7.5	Fibre Determination	38
3.7.6	Calcium and Potassium Determination	38
3.7.7	Phosphorus Determination (Spectrophotometric method)	39
3.7.8	Determination Iron (Fe) using buck 200 AAS	39
3.8	Efficacy of processing dried chips with Fermented maize water and lime	39
3.8.1	Preparation of Fermented Maize Water	39
3.8.2	Preparation of Lime Juice	41
3.8.3	Preparation of dried chips	41
3.8.4	Efficacy of the treatment on the developmental period and adult longevity of *A. fasciculatus* on different dried chips.	41
3.8.5	Efficacy of the treatment on the damage of A. fasciculatus on different dried chips.	42
3.8.6	Determination of quantitative phytochemical analysis of the treated samples	42
3.8.6.1	Determination of Tannin (A.O.A.C. 1984)	42
3.8.6.2	Determination of Alkaloids (Henry, 1993)	43
3.8.6.3	Determination of Saponin (Brunner, 1984)	44
3.8.6.4	Determination of Phenol	44
3.8.7	Influence of Treatment on Organoleptic Properties of Selected Dried Chips (Amala)	45
	CHAPTER FOUR	46
	Results	46
4.1	Occurrence of insects associated with the selected dried chips	46
4.2	Abundance of insect species associated with the selected dried chips	48
4.3	Diversity of insect's species associated with selected dried chips	53
4.4	Pesticide residues analyses in dried cassava and water yam chips from selected locations	60
4.5	Life history and description of the life stages of *Araecerus fasciculatus* on selected dried chips	75
4.6	Food host preference of *Araecerus fasciculatus*	81
4.7	Effect of choice and no-choice food preference on emergence of F_1	86

progeny
4.8 Weight loss assessment of *Araecerus fasciculatus* on dried chips 86
4.9 Assessment of qualitative and quantitative damage by *Araecerus fasciculatus* on selected dried chips. 90
4.10 Efficacy of processing dried chips with fermented maize water and lime 97
4.11 Quantitative Phytochemical Composition of the Treated Samples 101
4.12 Influence of Treatment on Organoleptic Properties of Selected Dried Chips (Amala) 107
CHAPTER FIVE 115
DISCUSSION 115
CHAPTER SIX 122
SUMMARY AND CONCLUSION 122
REFERENCES 125
APPENDICES 142

LIST OF TABLES

Table 3.1	Treatment application rate	43
Table 4.1	Occurrence of insects associated with all the food hosts	50
Table 4. 2	Abundance (Mean ± SE) of insects associated with cassava in 2016/2017 in selected locations in Nigeria	54
Table 4.3	Abundance (mean ± SE) of insects associated with sweet potato in 2016/2017 in selected locations in Nigeria	55
Table 4.4	Abundance (mean ± SE) of insects associated with water yam in 2016/2017 in selected locations in Nigeria	56
Table 4.5	Abundance (mean ± SE) of insects associated with white yam in 2016/2017 in selected locations in Nigeria	57
Table 4.6	Abundance (mean ± SE) of insects associated with plantain in 2016/2017 in selected locations in Nigeria	58
Table 4.7	Order/Family-wise percent composition of insects associated with cassava in 2016 and 2017 in selected locations in Nigeria	59
Table 4.8	Order/Family-wise percent composition of insects associated with potato in 2016 and 2017 in selected locations in Nigeria	60
Table 4.9	Order/Family-wise percent composition of insects associated with water yam in 2016 and 2017 in selected locations in Nigeria	61
Table 4.10	Order/Family-wise percent composition of insects associated with white yam in 2016 and 2017 in selected locations in Nigeria	62
Table 4.11	Order/Family-wise percent composition of insects associated with plantain in 2016 and 2017 in selected locations in Nigeria	63
Table 4.12	Diversity indices of insects associated with cassava in 2016/2017 in selected locations in Nigeria	64
Table 4.13	Diversity indices of insects associated with potato in 2016/2017 in selected locations in Nigeria	65
Table 4.14	Diversity indices of insects associated with water yam in 2016/2017 in selected locations in Nigeria	66
Table 4. 15	Diversity indices of insects associated with white yam in 2016/2017 in	67

	selected locations in Nigeria	
Table 4.16	Diversity Indices of Insects Associated with Plantain in 2016/2017 in Selected locations in Nigeria	68
Table 4.17	Mean Concentration (mg kg^{-1}) ± SE of organochlorine residues in dried cassava and yam chips from selected locations	70
Table 4.18	Mean concentration (mg kg^{-1}) ± SE and percentage of organochlorine residues detected in dried cassava and yam chips from selected locations	71
Table 4.19	Highest pesticide residues on dried cassava and yam chips from selected locations compared with EU's maximum residue limits ($mgkg^{-1}$)	72
Table 4.20	Developmental parameters (days) mean ± SE) of *A. fasciculatus* on selected dried chips	75
Table 4.21	Developmental Periods (days) (mean ± SE) of the larva stages of *A. fasciculatus* selected dried chips	77
Table 4.22	Morphology (mm) ± S.E of the life stages of *A. fasciculatus* on selected dried chips	78
Table 4.23	Head Capsule width for larval instars of *A. fasciculatus* and test for conformity to Dyar's rule	79
Table 4.24	Mean number of *Araecerus fasciculatus* associated with dried chips in choice host preference study after 24, 48, and 72 hours of infestation	83
Table 4.25	Effects of food hosts on developmental parameters (± S.E.) of F_1 progenies using Free Choice Experiment	84
Table 4.26	Effects of food hosts on developmental parameters (± S.E) of F_1 progenies using no choice experiment	86
Table 4.27	Mean weight loss (%) ± S.E of selected dried chips on Araecerus. fasciculatus infestation	89
Table 4.28	Mean of frass (g) ± S.E of selected dried chips on *A. fasciculatus* Infestation	92
Table 4.29	Effect of A. fasciculatus infestation on proximate composition of dried chips g/100 g	93
Table 4.30	Effect of *A. fasciculatus* infestation on mineral element of dried chips g/100g	94
Table 4.31	Phytochemical composition of the treated dried cassava samples	102

Table 4.32	Phytochemical composition of the treated dried potato samples	103
Table 4.33	Phytochemical composition of the treated dried water yam samples	104
Table 4.34	Phytochemical composition of the treated dried white yam samples	105
Table 4.35	Phytochemical composition of the treated dried plantain samples	106
Table 4.36	Sensory evaluation of treated cassava chips (Amala)	108
Table 4.37	Sensory evaluation of treated potato chips (Amala)	109
Table 4.38	Sensory evaluation of treated water yam chips (Amala)	110
Table 4.39	Sensory evaluation of treated white yam chips (Amala)	111
Table 4.40	Sensory evaluation of treated plantain chips (Amala)	112

LIST OF FIGURES

Figure 3.1	Map of state in south of River Niger with map of Nigeria inserted showing the study area where survey for *Araecerus fasciculatus* was conducted in 2016/2017	30
Figure 4.1	Hierarchical classification of insect pests on selected dried chips	69
Figure 4.2	Frequency distribution of the head capsule width of larval instar of *A. fasciculatus* on selected dried chips	80
Figure 4.3	Relationship between head capsule width and larval development stage of *A. fasciculatus* on selected dried chips	81
Figure 4.4	Percentage weight loss assessment of *Araecerus fasciculatus* on dried chips	87
Figure 4.5	Efficacy of the treatment on the developmental period of *A. fasciculatus* on selected dried chips	97
Figure 4.6	Efficacy of the treatment on the adult longevity of*A. fasciculatus* on selected dried chips	98
Figure 4.7	Efficacy of the treatment on the percentage damage of *A. fasciculatus* on selected dried chips	99

LIST OF PLATES

Plate 3.1	Food materials (A-E) used for biological study and damage assessment of *Araecerus fasciculatus* in Nigeria	32
Plate 3.2	Sliced chips of various root, tubers and crops and plantain after oven dried for biological study in the Department of CPEB, University of Ibadan	34
Plate 4.1	*Araecerus fasciculatus* larvae instars developmental period	76
Plate 4.2	Damaged dried chips caused by exit holes and feeding activities of *A. fasciculatus*	90
Plate 4.3	Sensory Evaluation test of the treated chips	107

CHAPTER ONE

INTRODUCTION

Yam, cassava, and sweet potatoes are tuber and root crops, as well as fruit crops like plantains, are among the most significant staple foods in Sub-Sahara region of Africa (Osei *et al.*, 2009). These are important in the diets of the vast majority of African population. They also play major roles in reducing food crises in Africa because they supply the bulk of energy in human and livestock diets, their availability all year round, tolerance to harsh environmental conditions and easy fit into the Africa farming systems (Sanginga, 2015; Ferraro, 2016). Root, tuber and fruit crops are very important in the diets of the West Africa and together they greatly contribute to efforts to reduce food insecurity in Africa (Isah *et al*., 2012). In tropical places around the world, tuber and roots crops are essential agricultural sources of energy after cereals. Sweet potatoes, cassava, aroids and yams from several botanical groups are among the examples. In Sub-Saharan Africa, various varieties of whiteyam, cassava, sweetpotato, wateryam, and plantain are grown (Isah *et al.,* 2012). The international Institute Tropical Agriculture (2013) reported that above 50 percent of the world's cassava, as well as the primary species of yams native to Africa, are grown in Sub-Saharan Africa's humid and sub-tropical regions. Exotic food like sweet potato and plantain have established themselves in Sub-Saharan Africa, utilized to alleviate food shortages. (Asuming-Brempon *et al*., 2011). Tuber and root crops as basic foods have a number of agronomic advantages, including their ability to adapt to a variety of soils, different environmental conditions, and farming systems with few agricultural inputs (Chandrasekara and Kumar, 2016).

Many households in Africa's rural areas based on tuber and root as both income and food source. The prominence of these crops as a source of monetary income for people and as 2016 (Kanamugire and Afadhali, 2017; FAO, 2017). Furthermore, various private sector processors also causes rising demand for tubers and root by producing cassava starch, sweet potato candy, and banana beer, among other things. Pests and diseases, soil infertility, market pricing that seem to be low, price swings, erratic rains, dryness, and a lack of clean planting material limits root, tuber, and plantain output (Okonya and Kroschel, 2015). Although there is universal agreement that insect pests and diseases play a crucial role in the spread of food shortages, there is limited data on yield and post-harvest wastage (Okonya *et al*., 2019).

According to Eke-Okoro *et al*. (2014), the most important staples food crops obtained and manufactured in Sub-Saharan Africa grains make up around 53% of the total, roots and tubers make up about 31%, grain legumes make up about 6%, and 5% each of groundnuts, plantains and bananas. In Nigeria, Ghana, Cameroon, Côte d'Ivoire, and republic of Congo; Over half of the food energy intake comes from roots and tubers. Food crop like sweet potatoes, sugar beets, Irish potatoes and cassava are among the 15 most important crops across the globe. They account for over more than 75% of global per capital daily caloric intake and 60% of global recommended daily protein supply per capital (Eke-Okoro *et al*., 2014). Pharmaceutical and industrial raw materials are also obtained from roots and tuber crops and they also have commercial advantage (Paulino and Yenug, 1981). Sub-humid and wet tropics of Sub-Sahara Africa produce above half of cassava and yam entire world's production (IITA, 2013). Africa produces the majority of root and tuber crops and are mostly produced by small scale farmers who rely on traditional non-mechanized methods (CABI, 2005). Most of the crops produced in Africa suffer high yield losses due to the numerous diseases and pests infestation (IITA, 2013). The world needs abundant food for survival but insect pests remain an important factor to field and storage production. In storage, insect pests infest commodities; resulting in losses in terms of quality, such as lower nutritive and market values, as well as the growth of mold and quantitative losses weight losses of over 30% in about one month of storage (CABI, 2005). Storage losses of dried chips vary according to region, environmental conditions, main pests, storage structure and method of storage (Kossou and Bosque-perez, 1998).

Storage conditions play a big role in large-scale root and tuber crop production. Because fresh tubers are perishable owing to microbial decomposition, physiological activities including sprouting, respiration and transpiration, and are influenced by the environment conditions, particularly relative humidity and temperature (Sanni *et al.,* 2009). According to Ferraro *et al.* (2016), in most cases, the storage stage results in significant losses, it can account for up to 25% of the total weight. In storage, infestation by insect is the leading cause of damages. Weight loss in preserved produce has been linked to a variety of insects that depend directly on the dried chips (Osunde, 2008). To keep the moisture level as low as possible, dry yams are made from freshly harvested yams in order to avoid losses; as a result, obtaining chips and flakes is common (Jonathan *et al.,* 2011). Omohimi *et al.* (2017), reported that peeling of yam back, followed by slicing, blanching in hot water, steeping, and sun-drying was all used to made dried yam chips. Yam flakes are made similarly to yam chips, with the exception that the drying method is faster because of the flakes' size. Yam flakes and chips can be ground into flour; the latter can be put together with hot water to make a sticky dough, which is used as a carbohydrate source for meals in tropical locations (Ayodele *et al.,* 2013).

In an attempt to reduce post-harvest losses, these products are converted into chips, dried adequately and stored for certain periods of time until needed. The main objectives of preparing tubers into dried chips by farmers are to reduce deterioration and physical damage after harvesting, remove parts that are not edible and marketable, earn substantial income, to reduce costs of transportation, and to provide agro-industrial raw materials (Ferraro *et al.,* 2016). Some of the insect pests that are associated with dried tubers and chips include *Araecerus fasciculatus*, *Prostephanus truncatus*, *Rhysopertha* and *Dinoderus* species. Among these insects, the Coffee bean weevil, *A. fasciculatus*, is major concern and it poses problems to many agricultural produce and products (Chalmers, 1983). Research has shown that this weevil is polyphagous as it infest coffee, cocoa, groundnut, maize grains dried fish and chips of cassava, water yam, sweet potato, plantain and whiteyam (Woodruff, 1980; Alba-Alejandre *et al.,* 2018).

Arbogast *et al*. (2002) described *A. fasciculatus* is has ability to damage a variety of high-value agricultural goods and products, such as coffee, cocoa, and nut megs, dried yams

and cassava chips, Brazil nuts, groundnuts, maize. Rees (2007) also described *A. fasciculatus* as a major insect pest that can attack healthy cowpeas, allowing other pests to attack them. To minimizing pre- and post-harvest food losses, effective pest and disease strategic can help and thereby increase food output (Iqbal, 2017). Information on pests and diseases that are currently associated with dried chips and the extent of destruction will be extremely valuable in policy and research in order to establish long-term control methods. Nonetheless, there is a dearth of information on the biology, ecology and control of this insect, as well as the population dynamics of *A. fasciculatus* on different hosts. Furthermore, reports on damage and weight loss assessment of the insect pest on cassava, white yam, water yam, sweet potato and plantain is lacking, hence the need to study the biology and ecology of *A. fasciculatus* on different hosts.

The general objective of this research was therefore to determine the bioecology and management of *Araecerus fasciculatus* De Geer with fermented maize water on selected food hosts in selected locations in Nigeria and to evaluate pesticide residues available in these chips.

The specific objectives were to:

1. Survey for occurrence, abundance and diversity of the insect pests associated with dry chips of cassava, sweet potato, water yam, white yam and plantain in selected States in Nigeria;
2. Evaluate pesticide residues in the dried cassava and yam chips in selected locations in Nigeria
3. Study the life cycle characteristics of *A. fasciculatus* on dried chips of white yam, water yam, cassava, plantain and sweet potato.
4. Assess the qualitative and quantitative damage of *A. fasciculatus* on dried chips of white yam, water yam, cassava, sweet potato and plantain.
5. Evaluate the efficacy of processing dried chips of selected tubers and plantain with fermented maize water and lime juice on reducing infestation and damage by *A. fasciculatus.*

CHAPTER TWO

Literature Review

2.1 Insect pests associated with root and tuber chips

Yam, sweet potato, cassava and plantains are predisposed to insect pest infestation after being processed into chips, dried, and stored for short or long durations until required, posing a danger to availability of food in Sub-Saharan part of Africa. Insect infestation is the leading cause of post-harvest damage during chip storage. Weight loss in storage has been attributed to a variety of insect species that depend primarily on the dried chips in the store. Insect pests that mostly damage chips consist of the order Coleoptera (Beetles and Weevils), its members are characterized by the development of strong mandibles or snouts which they can use to slash or cut into wood and other plant materials directly (USDA, 2012). *Tribolium castaneum*, *Rhyzopertha dominica*, *Stegobium paniceum*, *Araecerus fasciculatus*, *Prostephanus truncatus*, *Ahasverus advena*, *Dinoderus minutus* are among the key post-harvest pest (Waller *et al.,* 2007; Osunde 2008; USDA, 2012).

Girardin (1996) and Sanginga (2015) specifically stated that in store; bored insects infest yam chips often, causing significant damage in a matter of months. The most common among these are *Sitophilus zeamais* (Motshulsky), *Araecerus fasciculatus* (Degeer), *Dinoderus oblonguntatus* (Lesne), and *D. minutus* (Fabricius) as well as *Palorus subdepressus* (Wollaston) (Osunde, 2008). Alba-Alejandre *et al.* (2018) also stated that *Araecerus fasciculatus* (De Geer) and *Sitophilus zeamais* (Motshulsky) are perhaps the most popular. Slices of dried yam receiving at mills are frequently full with holes produced by the previous insect, and stores where yam flour is stored in regular bags are frequently infested with one or both species (Alba-Alejandre *et al.*, 2018). Whereas,

Sitophilus zeamais infests grains such as maize, rice, sorghum, the most significant pest of dried chips is *A. fasciculatus*.

2.2 History and Significance of *Araecerus fasciculatus* De Geer

Araecerus fasciculatus De Geer, also refered to as Coffee bean weevil, is a cosmopolitan important pest in warehouses and store. The pest can be found in both tropics and subtropics regions; the insect has been identified to be a tropical pest of dried chips, stored grains, stored seeds of coffee and cacao (Valentine, 2005). *Araecerus fasciculatus* is an ancient genus with at least 59 mostly identified species and the fact that coffee was introduced around the world in the 18th century enhances its cosmopolitan status. *Araecerus* was referred to as Coffee Berry Borer (Usman, 1949) and was considered as a destructive insect that wreaks havoc on dried Manihot and other preserved crops (Hill, 1990; Osunde 2008). .

Araecerus fasciculatus was described by Alba-Alejandre *et al.* (2018) as an important stored product pest, also destroys many dry materials (Merdelyn *et al*., 2011). However, from the 1920s, some literature reported that *A. fasciculatus* also infest growing plants or soft fruits in the tropics. It was also described by Archibald and Chalmers (1983) to be among the product that has been intercepted and kept Coleopteran in New Zealand. Papaya was mentioned as one of the host plant on which it was found. According to history, *A. fasciculatus* is a polyphagous pest and it is not restricted to only coffee beans as its common name implies but was found infesting many stored produce.

2.3 Biology of *Araecerus fasciculatus* De Geer

Iqbal (2017) described Coffee bean weevil as a small dome shaped beetle with dark brown to black colour and a major pest of stored produce. Adult *A. fasciculatus* body length ranges from 2.5 - 5mm, (Cotton, 1921 and Sayed, 1940; Ardakani and Nasserzadeh, 2014; Alba-Alejandre *et al.*, 2017); body shape is spherical, the antennae is long with three segments creating a club, long legs, and light and dark markings on the elytra; elytra is short to expose the last abdominal segment. Eyes are unnotched and whole, and the bark is small and thin. The antenna has eleven segments, with the three apical components being

larger than the others. Adult have a bruchid appearance. The wings almost cover the abdomen, but leave the last segment exposed. *Araecerus fasciculatus* sex ratio is 1:1 (Walker, 2007). Female pygidium (caudal shield covering the abdomen) is inclined and distinctly visible dorsally while in males the pygidium is vertical, not distinctly visible dorsally (Ardakani and Nasserzadeh, 2014).

The pupa of *A. fasciculatus* was described by Cotton (1921) to be whitish when first formed and the molt larva skin stick or hold tightly to the last abdominal segments. On cocoa *A. fasciculatus* Pupa are around 3.75mm to 4mm long and 2mm wide, it has a round hairy Head with short and broad beak, wings are covered and armed with hair. Each of the pupa abdominal segments comprises of ventral and lateral hairs in two lines. The seventh and eighth abdominal tergites appear to be connected; two enormous bilobed fleshy processes equipped with many papillae make up the ninth segment. The tenth segment is more ventral than the ninth. Tips of pupa wings have a pointed end and are terminate with a long chitinized hook which is about to reach seventh abdominal segment (Ardakani and Nasserzadeh, 2014).

Araecerus fasciculatus larva is white in colour, footless, wrinkled, and fleshy and with a curved body covered with long hair, can measured 4.5–6 mm in length when matured. Larva's head is flat or rectangular in shape with a very pale straw colour. The five instars of the coffee bean weevil can be differentiated by the size of the cephalic capsule. (Cabal, 1952; Alba-Alejandre *et al*., 2018). The mandibles anterior margin are slightly darker, mandibles are strong, triangular, thick and large, with the peak produced into an acute tooth. *Araecerus fasciculatus* larva comprises of ten abdominal segments. Spiracles are located on Segment one to the eighth. The eight abdominal segment spiracles are located posteriorly with air tube pointing to the anterior. The ninth segment is very small while the tenth is reduced. A conspicuous black area beside the exoskeleton represents the eyes of larvae (Caasi-Lit and Lit, 2011; Ardakani and Nasserzadeh, 2014).

According to Ardakani and Nasserzadeh (2014), *A. fasciculatus* length and width of an egg are around 0.56mm and 0.35mm, respectively, white, shinning, and has an ovate shape. It has a broadly rounded top with a slightly pointed bottom. Study conducted on nutmeg shows that it produced more females to males (Sahed, 1935). Female can lay

about 60 eggs and the larva emerges in about 5 to 20 days. Life cycle ranges from 21-80 days, depending on environmental conditions and preference of the food host. After emergence it takes 6 days and 3 days for females and males to matures physiologically and sexually respectively at 27^{o}C. Fertilization also occurred in about 6 days with a duration of 6.5–8 min., at 27^{o}C. The study conducted on maize reveals that *A. fasciculatus* oviposition occur on the average of 8 min. (at 18^{o}C.) Unfertilised eggs are laid on the food surface and are not inserted into the food. According to Saheed (1935), incubation period ranges from 5–8 days at all humidity, total life cycle ranges from 42- 57 days. The coffee bean weevil is 4–5 mm long (Alba-Alejandre *et al*., 2018), stored products pest with a worldwide reach and over 100 hosts (Mphuru, 1974). Females lay an egg 1–2 mm deep in stored coffee beans and the larvae consume the bean (Walker *et al.,* 2007). De Figuereido Jr. (1957) observed a 30 percent loss in coffee kept for six months and CABI, (2017) observed 20 percent loss at nine months after storage.

2.4. Distribution and economic importance of *Araecerus fasciculatus* De Geer

Most tropical areas of the earth are suitable for *A. fasciculatus.* (Haines, 1991; Caasi-Lit and Lit, 2011; Ardakani and Nasserzadeh, 2014). It was considered to have its origin in India, the East Indies, and other places. Its occurrence, however, is becoming more or less global (Grout *et al.,* 2001). Degeer first described *A. fasciculatus* in 1775, while Lucas described it in 1861. In France, it was observed digging through Chinese ginger branches. Now, *A. fasciculatus* is found in the United States, St Helena, Brazil, Persia, Nigeria, Japan, Kenya and Ghana, among other places. (Mphuru, 1974; Grout *et al.,* 2001). Cherries, copra, sorghum, coffee beans, rice, cassava chips, maize, coffee, millet and groundnut have all been documented to be damaged by this insects etc. In Africa*, A. fasciculatus* has been observed destroying cotton bolls and seeds, damaging cocoa in the Gold Coast during the process of drying and storing, (Patterson, 1928), in coffee berries in the Dutch East Indies (Friederichs, 1925) and also damaged Brazil nut (Gater, 1925).

Araecerus fasciculatus is a major pest of coffee, both freshly prepared and stored (Chijindu and Boateng, 2008). It is a major pest in various South American countries, resulting in significant losses in fresh coffee (Wrigley, 1988). Currently, *A. fasciculatus* is a severe threat to Ghana's cocoa economy. It infests high-moisture-content cocoa beans.

By feeding on the bean, this pest causes damage to stored products, lowering its vitality. It also feeds on the cotyledon, reducing the product to powder or causing the produce to lose weight. (Appert, 1992). In a laboratory experiment, conducted by Azalekor (1999), it was found that 13.34% damage occurred in cocoa stored in jute sacks over a period of 4 months, apart from other forms of losses recorded. The adult and larvae both impact negatively on stored food. The larvae spend their whole developmental period inside of the bean or grain, eating about a third of the bean or grain. Yam and cassava chips are also adversely affected by this insect in terms of quantity. (Haines, 1991; Stumpf, 1998; Cassi-Lit *et al*., 2011; Alba-Alejandre *et al.,* 2018).

2.5. **Taxonomy of the Coffee bean weevil: *Araecerus fasciculatus* (De Geer)**

Araecerus fasciculatus is the only member of this family (Anthribidae) that is of high economic value in storage; most other insects belonging to this family consume fungi and decayed wood (Haines, 1991; CABI, 2017). The adult is 3-5mm long and dark brown to grey brown in colour (Wrigley, 1988, Haines, 1991; Iqbal 2017). The prothorax and the elytra bear many light brown circular patches, the insect is oval and convex, it is covered with a pubescence and the elytra are slightly shorter than the abdominal segment. This leads to one abdominal segment getting exposed (Iqbal, 2017). The antennae in the matured adults are long, thin and end in three thick blackish joints and are held forward. The head is somewhat pointed with prominent eyes. The larva measures between 4.5 - 6 mm in length. It has a narrow, apodal, and hairy body with an ochre head. (Wrigley, 1988; Appert, 1992). Walker, (2007) described the scientific classification of *A. fasciculatus* as:

Kingdom: *Animalia* - C. Linnaeus, 1758 - Animals

Phylum: *Arthropoda* - Latreille, 1829 – Arthropods

Class: Insecta

Order: *Coleoptera* - C. Linnaeus, 1758

Suborder: *Polyphaga* - Emery, 1886

Family: *Anthribidae* Billberg, 1820.

Genus: *Araecerus* - Schönherr, 1823

Specific name: *A. fasciculatus* – De Geer 1973

2.6 Occurrence of *A. fasciculatus* on Crops and Plant Products

Araecerus fasciculatus attacks variety of field crops and those in store in all around the world (Childers and Woodruff 1980; Iqbal, 2017). The insect is a primarily stored products pest, but also occur on plants or fruits (Childers and Woodruff, 1980). Presence of *A. fasciculatus* was reported on healthy and dried oranges in between 1929 and 1944 in Florida, Louisiana, and California (USDA, 1971), in Florida immature stages of *A. fasciculatus* was discovered on the fruit when there was excessive fruit drop prior to harvest (Woodruff, 1972). Mphuru (1974), Grout *et al.,* (2001) and CABI (2017) stated that cassava is one of the products that has been attacked by the beetle, dried plantain, sweet potato and various seeds and fruits and is also a remarkable insect pest of coffee in India and Central America and of stored cocoa in West Africa. Nagano (1981) reported that in Japan, the beetle was discovered attacking garlic bulbs and field coffees berries in Brazil.

Childers and Woodruff (1980) reported the beetle as an important stored-product pests, such as dried chips, maize, spices, cocoa, nutmeg, nuts, coffee grains, groundnuts and dried fruits in the tropics. Adesuyi (1967) and Osuji (1980) discovered *A. fasciculatus* damaging preserved yam chips and flour in Nigeria. Iheagwam (1986) also described the pest as a significant yam tuber pest during storage. Chijindu and Boateng, 2008 found the pest on stored cassava chips. Lin (1976) also reported the beetle as an important pest of maize during storage, sweet potato and the medicinal herb- chiretta - (*Liqusticum acutilobum*).

2.7 *Araecerus fasciculatus* as a Storage Pest

Araecerus fasciculatus De Geer is known to cause severe damage to several dried farm produce in store including coffee, cocoa, cassava, yam, sweet potato and plantain (Childers and Woodruff, 1980; Palaniswami and Peter, 2008; Iqbal, 2017), it deposit its eggs on hosts and the larvae dig inside and consume the contents. It Pupate inside the hosts and the adults emerge, through emergence holes on the tuber surface. Robert and

Woodruff (1972) reported that it has 28-32°C optimum temperature range for growth and development but the moisture content of the produce greatly influenced rate of development and mortality. The beetle completed its life cycle in 66 days on cocoa and 43 days on maize at 27°C and 80% RH as minimum limit for development and also reported its attacks on many stored commodities like nutmeg, maize, dried chips of tuber crops, dried fruits, ginger, cocoa beans and coffee when they are not dried properly most especially in the tropics. The pest also attacks the cotton bolls, banana and custard apple fruits (Robert, 1972).

The beetle is considered as an important pest of whole tubers and chips, cassava during drying period especially in the tropics (Beevi *et al.,* 1991; Iqbal, 2017). The lifecycle appears to be variable, depending on climate and host, but is generally completed about 45- 60 days (Robert, 1972; Iqbal, 2017). Adults live for several months, feed on fungi, and cause little or no damage. They jump or tumble when disturbed and often feign death for a short time (Kumar and Karnavar, 1986).

2.8 Control Measures Against *A. fasciculatus*

The most effective ways of controlling coffee bean weevil are the practice of good store sanitation and proper drying of stored produce. Adesuyi (1967) reported that dried yam chips require appropriate store cleanliness during storage to control infestation and Cotterell, 1952 reported that the level of infestation has reduced drastically due to improved drying conditions. Fumigation is another technique practiced to control this pest. Stores in Nigeria are usually fumigated with methyl bramide (Quereshi, 1966). In Brazil, it was determined that fumigating a coffee house with phosphine tablets was efficient against every stage of A. fasciculatus (Puzzi and Orlando, 1963 and 1964). Pyrethrum was prescibded in India by Subrahamanyan (1963) for the fumigation of coffee and DDT, Chacko and Bhat (1979) successfully used emulsion concentrates of malathion and phoxin to impregnated jute bags, used in the storage of coffee. Bitran *et al*. (1978) also discovered malathion and tetrachlorvinphos effective in the treatment of stored coffee. Contact toxicity of 27 insecticides against the adult beetles was evaluated by Childers and Nigg (1982), ten of the compounds with LD 50 in the range of 5.6 to 58.7 mg/g was found

active. The compounds were Phosmet, fenvalerate, methidathion, azinphosmethyl, oxamyl, bendiocarb, permethrin, phenthoate, SD35 651 and carbosulfan.

2.9. Yam *(Dioscorea* spp) (Origin, Production, Utilization)

In West Africa, Caribbean and Southeast Asia, yam (*Dioscorea sp*.), a monocotyledonous, a main food, belonging to the family Dioscoreaceae. (Liu *et al.,* 2007). Cooking of raw yam, cooked yam soup, and powdered or floured yam are all common ways to consume yam. In many regions, yams (*Dioscorea spp*.) are a main food. In Sub-Saharan Africa, they are the third most popular crop, particularly in West Africa (Eke-Okoro *et al.,* 2014) and also widely popular in the South-East Asia, India, South Americas and South-East Asia (Ferraro *et al*., 2016). For generations, yams were a reliable source of sustenance, particularly prior to the cereals introduction. (Scott *et al.,* 2000).

In the tropics, yam is widely grown and in various East Asia and South America countries (Iwueke *et al.,* 2003). They have been reported to originate from Asia and Africa (Idumah *et al.,* 2014). Yam is ranked second most significant tropical native plant after cassava in West Africa, in the research about carbohydrates, it matures annually whereas some varieties are perennial depending on the species (Opara, 1999). Yam is of the genera "*Dioscorea*" and family "*Dioscoreaceae*" Yam is seasonal; the fresh yam is highly perishable and is among the most important food crop (Babajide *et al.,* 2010).

In 2017, 73 million tonnes of yam were produced worldwide over an area of 8.6 million hectares. Africa accounted for over 97% with 71 million hectares. Nigeria produced about 67.5% of the amount produced in Africa and 65.7% of the total amount produced worldwide, Nigeria produces the largest yam quantity in the world., with 47.9 million tonnes produced over 5.9 million hectares. (FAO, 2019). Gruēle *et al.* (2006) described yams as herbaceous, twining, climbing, perennial and monocots; which comprises of many climbing vines with tuberous root, they are starchy and occurr naturally or cultivated in warm regions. There exist over 600 species of yam in the world but Idumah *et. al*. (2014) considered six important edible species in the tropics, these includes *Dioscorea rotundata*, *D. cayenensis*, *D. alata*, *D. dumentorum*, *D. bulbifera* and *D. esculenta*. Some species are cultivated for pharmaceutical purpose. There is presence of

organoleptic qualities on the tubers which contributed to its preference as carbohydrate staple. Yam provides carbohydrate to the body system, is planted in Africa, Asia, Latin America and Oceania. In the Nigerian economy, yam constitutes one of the important tuber crops in cultivation and yield. (Bamire and Amujoyegbe, 2005).

Yam is a major in religious belief and religious ceremonial for various tribes in Nigeria. It is a basic household main food, ceremonies and industries. Yam tubers are consumed boiled, pounded, chipped, roasted, fried, sun dried and process into yam flour (Jakubczyk, 1982). Water yam, *Dioscorea alata* is used in Southwestern Nigeria by the Ijebus to prepare a delicacy known as Ikokore. In Nigeria many of the tribal cultural belief are attached to yam, such as weddings, social ceremonies, annual celebration of new yam festivals in rural and some urban communities (Izekor and Olumese, 2011).

Cultivation of yam is being done on fertile soil and can be sandy or free drained. Land preparation can be in the form of ridge of 1m (3 ft 3 inch) height, these soil conditions are highly recommended for water yam, white yam or yellow yam. Cut setts or seed yam from storehouse can be cultivated, prior to planting fungicide (thiabendazole) or wood ash are used to treat planting tubers before planting to prevent damage or spoilage. Orkwor *et al*. (1997) conducted a survey and discovered when that during yam chips production, the leaves of *Piliostigma thonningii and Cussonia bartei* when added to yam during parboiling increases dried yam chips quality and duration of storage.

2.10 Constraints to Yam Production

Financial constraints, and high labor costs, scarcity and high cost of quality planting material, inadequate modern technology, fertility issues, infestation of insect pests and diseases, high transportation costs, and poor storage facilities are major challenges to yam production (Omojola, 2004). There are many species of insects that attacks yam in various locations of the earth, 49 species was reported to attack yam in the field while 27 species affect yam in storage after harvesting few Coleoptera and mealybugs are economically important due to their ability to retard crop growth in the field and are responsible for severe tubers loss in storage (Korada *et al.,* 2010). Furthermore, there is the problem of

high operational cost of land preparation, staking, weeding during growing period and high cost of harvesting.

2.11 Methods of Yam Processing

Processing of yam is highly essential due to significant storage losses resulting in deterioration and rotting of the tubers (Onayemi and Potter, 1974). During storage, after about 2-3 months, a fresh yam starts to decay. (Babajide *et al.*, 2010). In Nigeria, postharvest yam losses were amounted to be around 37% (Alimi *et al.*, 2013). Yam has high potential for use in the preparation of various delicacies in the industry (Amandikwa *et al.*, 2015). The traditional method of processing yams to dry chips and thereafter to yam flour is still in existence, but the quality of yam chips produced depends on the producers and locations where they were being produced (Mestres *et al*., 2004).

To prepare yam chips, the tubers are peeled, cut into a size of about 1 cm and parboiled before sun or wind drying, so as to make the tissues soften for better and palatable yam flour. Drying takes about 2-5 days and can be much longer like two or three weeks (Mestres *et al*., 2004) depending on the prevailing environmental condition. After drying the chips, they may be stored, ground with grinding machines or ground in mortars and later sieved to give smooth flour. During storage the main problem of dried chips and yam flour is insect infestation, most especially *Sitophilus zeamais*, *Araecerus fasciculatus* as well as rodent attack on whole chips. Losses experienced during storage are greatly influenced by the methods used during processing period and the management of dried chips in store. Nwana and Azodeh (1984) reported *Araecerus fasciculatus* (De Geer) damage on blanched yam chips were low compared to unblanched chips, Blanching kills or renders enzymes inactive; else, in storage, chips may be discoloured and produce off-flavors and aromas. (Sablani *et al*., 2006). To prepare yam flour for consumption, it requires mixing the flour with boiled water and stir till a paste is formed.

2.12 Origin, Utilization and Production of Cassava (*Manihot esculenta*)

Cassava has been the highest popularly grown root crop, and its cultivation is restricted to the tropics and subtropics due to its prolonged growth period (8–24 months). It is an Euphorbiaceae family that grows as a perennial shrub. There are 98 species in the genus

Manihot, with M. esculenta being the most extensively grown. (Nassar *et al*., 2008). Cassava is a root crop, its origin is South America, later, it extended over Africa and Asia's tropical and subtropical climates. (Blagbrough *et al.,* 2010). Because of its high carbohydrate content, cassava is an essential main food for more than 500 million people globally. (Blagbrough *et al.,* 2010). Cassava was introduced by the New World to Tropical Africa (Roger, 2014).

In 2017, 292 million tonnes of cassava were produced worldwide over an area of 26.3 million hectares, the country with the highest level of cassava production were Nigeria 59, (485,947 tonnes) 20.4% of the total world production, Congo (31,596,046 tonnes) 10.83% of the total world production, Thailand (30,937,292 tonnes) 10.61% of the total world production, Indonesia (19,046,000 tonnes) 6.52% of the total world production, Brazil (18,876,470 thousand tonnes) 6.47% of the total world production. Africa accounted for about 61% of this with a production of 178 million tonnes over an area of about 20 million hectares. Nigeria contributed about 33% of the total production in Africa and 20.4% of the total production worldwide with a production of 59 million tonnes on a total area of 6.8 million hectares (FAO, 2019)

In southwest Nigeria the most important and popular root crops cultivated by arable farmers is cassava (Ogbe *et al*., 2007). In Nigeria, more than 60 million of the population depends on cassava as primary food source (Abdulahi, 2003). It is an important carbohydrate (Alvees, 2002; Nweke, 2004) food majorly for people living in West and Central Africa's lowland tropical and sub-humid tropics (Tsegia *et al*., 2002). Cassava grows in different types of soils including soil that is deficient in nutrients for other crops to grow (Asadu, 2004) and usage of cassava stem as planting materials is an added advantage to farmers because its stem is used unlike others that the part that are consumed are used as planting materials, In terms of calorie consumption, it was second to maize. (FAOSTAT, 2009). Major part of cassava consumed is tuber and is consumed in variety of ways; cooked and eaten raw, or used in making tapioca, abacha, lafun or garri or changed into other desired African delicious food, example include kokonte and fufu in Ghana (Amoah *et al*., 2010) or amala in Benin Republic and Nigeria. Pounded cassava with vegetables soup is a delicacy food especially in southern part of Nigeria its leaves are

also used to prepare soup. It can be stored sun-dried as dried chips, to extend their usage during the off-season and also to make delicacies (Isah *et.al*., 2012)

Cassava chips can be made directly from tubers of low or medium cyanide varieties can be used by passing cassava flour through a dough-making and frying process (IITA, 1987). Cassava flour is also used in the baking industries (IITA, 1988). Tubers from the cassava cultivars considered sweet can be eaten simply boiled or baked (Dufour, 1987). Cassava can also be used as biofuel, animal feed compound also in agro-industries (e.g. adhesive, starch, biscuits, ethanol, bread, fructose/glucose syrup and chinchin), the use of peels in the creation of organo-mineral compounds (Iyagba, 2010), peel to feed animal and used as raw ingredients in a variety of sectors, including livestock feed mills, confectioneries, fabrics, and breweries. (Kormawa and Akoroda, 2003).

2.13 Constraints to Cassava Production

Production of cassava is majorly constrained by problems of pests and diseases such as mealybugs, green mite, root rots, cassava bacterial blight, cassava mosaic disease, cassava anthracnose disease, and cassava bud necrosis etc. lack of capital, scarcity of cuttings, livestock damage, poor soil conditions, problem caused by fertilizers over dosage, land dilapidation, weed problem and weather-related problems are major constrains to cassava production.

2.14 Methods of Processing dried Cassava Chips

There is presence of cyanide inside fresh cassava, a substance that is poisonous to human and an animal, processing of fresh cassava is important in order to reduce the percentage of cyanide present for safety consumption (Eggleston *et al*., 1992). Fresh cassava can only be stored for few days because they are highly perishable after harvesting (Ihekoronye *et al*., 1985). Therefore, drying is done to increase its life span and reduce post-harvest losses, adding value, improving its storage (Westby, 2002) and also helps in reducing the cyanogenic glucoside content (Jakubczyk, 1982). To prepare cassava dried chips, peel and wash cassava root, then cut into smaller sizes for faster drying, soaked for 3-5 days before drying. Drying can be done in the sun or in a controlled environment such as an oven.

Prepared chips are essential in the manufacturing of starch and animal feed and for human consumption.

Different traditional techniques have been developed for cassava processing, for example Nigeria and Tanzania, prefer fermentation of cassava chips before sun-drying (Oyewole, 1992;), some parts of India prefer parboiling of cassava before drying to obtain a gelatinize texture (Rajamma *et al*., 1994), but in Ghana, direct sun-drying without fermentation is adopted (Stumpf, 1998). In Angola the cassava root is being soaked and dried after which it gound into flour called fuba (Alberto, 1958). In Nigeria dried cassava chips is ground into flour called lafun (Oke, 1965).

In some part of Africa and Asia, the most widespread and simplest method for preparing cassava chips for storage is by sun-drying and when needed ground into flour (Alberto, 1958) or stored in form of flour. Drying of cassava takes range of 3-10 days but when there is an extreme sunny day it can take 1 or 2 days and can be stored for 3-6 months. During storage dried cassava chips usually experience moulds and insects infestation which normally start when drying (Parker *et al*., 1981).

In West Africa and India parboiling chips before drying is their common practice which hasten the drying period and helps to store cassava chips for up to 12 months (Hiranandani and Advani, 1955; Doku, 1969). Processing methods used to prepare cassava chips from root to dried chips is reported to greatly influence damages experienced during storage and other means of susceptibility to insect infestation. Rajamma *et al*., (1994) reported that parboiled cassava chips have lower susceptibility to *A. fasciculatus* than plain sun-dried chips. In another research work by Rajamma *et al*. (1996) they discovered lower infestation of *A. fasciculatus* on unfermented chips. More so, the resistance of cassava dried chips to infestation by insect varies depending on both the processing method used after harvesting and the qualities of the variety used.

2.15 Origin, Utilization and Production of Sweet Potato (*Ipomoea batatas*) (L.) Lam.

The sweet potato was originated from parts of Mexico in Venezuela (Ecocrop, 2010) However, it is now common in tropics and subtropical nations worldwide. It rated seventh most essential food crop in the planet, and it is cultivated in tropical, subtropical, and warm temperate climates. Sweet potato is among the seven food crops, more than 100 millions tones are produced every year (FAO, 2015). Sweet potatoes could be cultivated all year under favourable weather, and adverse crop loss under unfavorable weather is uncommon; as a result, it is regarded as an "insurance crop." Sweet potatoes are a common food supporting crop for impoverished people because they can be gathered in little amounts over a lengthy period of time. (Chandrasekara and Kumar, 2016).

Major producing countries in different continents are Asia: Vietnam, India, China, Indonesia, Philippines and Japan, Africa: Uganda, Nigeria, Angola, Tanzania, Rwanda, Mozambique, Burundi and Madagascar and Americas: Brazil and USA. In 2007, 113 million tonnes of sweet potatoes were produced worldwide over an area of 9.2 million hectares. The leading producers are China (71.8 million tonnes), Malawi (5.47 million tonnes), Tanzania (4.24 million tonnes), Nigeria (4.01 million tonnes) and Indonesia (2.02 million tonnes). Africa produced about 24.6% of this with 27.7 million tonnes produced over an area of 4.7 million hectares. Nigeria accounted for 14.5% of the amount produced in Africa and just 3.6% of the total amount produced worldwide with a production of about 4 million tonnes in an area of 1.6 million hectares. (FAOSTAT, 2019).

Sweet potato produces adventitious roots, which are located within 25 cm deep inside the soil. It comprises of varying elongated starchy tubers on the root, variety determine the colour and texture. Sweet potato flesh comes in a variety of colors: white, purple, orange, and yellow while the skin ranged from purple, red, white and brown. It has slender vine that crawl up the sides; the stems can be up to 4 meters long. The leaves can be purple or green in colour, palmately veined, cordate, petioles are long and slender with pale violet or white flowers, sympetalous, axillary, solitary or in cymes. Sweet potato has a round fruits, comprises 1-4 seeded pods containing flattened seeds which are cultivated usually as an alternative food but sometimes as a staple food.

It is cultivated in Africa to prevent famine or for food security mainly because they develop fast require less work and input (Scott *et al*., 1993). The content of starch in sweet potatoes tubers is high; the tubers can be eaten raw, as well as boiled or fried, baked, dried and ground into fine texture to produce bread, biscuits and other pastries. Sweet potato leaves can be eaten as a vegetable (Duke, 1983). In USA Because of their high beta-carotene content, certain sweet potato is utilized as a natural dye or as a healthful snack. Presence of high-grade starch made them popular in the food industry and is also utilized in the drug sector (Chittaranjan, 2007). Sweet potatoes are also used as a feed source for all types of animals. (Woolfe, 1992). Pigs and cattle both enjoy the tubers. In 2007, livestock or the starch industry received half of the sweet potato tuber produced (Lebot, 2009; Chittaranjan, 2007). It can also be utilized as a stand-alone crop or as part of ingredients for industrial feeds (Gupta *et al*., 2009). Potatoes are grown as a source of energy and can also be used make alcohol through fermentation (Woolfe, 1992). Sweet potato tubers are mainly used as a source of energy, due to its high quantity of carbohydrate, which contribute for 80-90 percent of their dry weight. Sugars, Starch, small quantity of pectins, cellulose and hemicelluloses make up these carbohydrates (Lebot, 2009). Sweet potato comprised of 30 percent dry matter when tubers were fresh, with some kinds reaching up to 45 percent. Tubers are low in lysin and have a crude protein content of around 4% DM (Dominguez, 1992)

2.16 Methods of Processing Sweet potato

In many developing countries, sweet Potato was ranked among the most essential foods and are highly perishable (Ahmed *et al*., 2010).; in other to extend the uses and to reduce losses due to its perishability, fresh roots can be dried to make flour. Drying is the process of removing water from fresh food that is prone to microbial development (at water activity levels of 0.9 to 1.0) and reducing it to a healthy level near 0.6 (Oliveira *et al*., 2015). Drying is a vital part in maintaining a wide variety of products. (Chemkhi *et al*., 2005). Sweet potatoes are traditionally consumed after heat treatments such as boiling and frying, peeling, slicing, grating, pounding, milling. For instance, sweet potato may be peeled before cooking or cooked before peeling. However, it may be utilized in various ways; boiled and pounded with either boiled or fermented cassava as "fufu" or boiled

together with yam, boiled and eaten with stew, sliced into chips and then fried in vegetable oil, sliced into chips dried and boiled with beans or vegetables, dried and milled for sweetening of gruel or "ogi" porridge. Dried sweetpotato chips constitute very important staple source of food throughout the year's drier months, when the other sources of carbohydrates are still out of season (Bashasha *et al.,* 1993).

MacDonald (1970) reported that in a few East African countries where the dry season is pronounced some tubers are peeled, sliced, sun-dried and stored. Dried sweet potato chips are however subject to pest attack after 2-3 months of storage. (Agona, 1995). Tubers are usually cooked for one hour prior to drying and the dried chips can be stored for up to two years without getting spoilt, when the need arises the chips are washed and boiled. Snacks made with dried sweet potatoes have been reported by Yen (1974) In the Philippines. Sweet potato flakes are produced for storage and ground into flour as needed for use in gruel production. The tubers are also often utilized as a starchy food crop alternative in processing stages.

2.17. Origin and Production of Plantain

Plantain (*Musa acuminate)* originates from Southeast Asia, Plantains are grown above nine million hectares annually and world yield calculated at 102 million tons (Zeller, 2005). Countries with the highest level of plantain production were Uganda (4.6 million tonnes), Cameroon (4.1 million tonnes), Ghana (3.9 million tonnes), Colombia (3.6 million tonnes), Nigeria (3,163 thousand tonnes). In 2017, 39.2 million tonnes of plantain were produced over an area of 5.5 million hectares. Africa generated roughly 60% of the total, with 23.6 million tonnes produced over 4.1 million hectares. Nigeria accounted for about 13.4% of the amount produced in Africa and about 8.1% of the total amount produced worldwide with 3.2 million tonnes in an area of 499 thousand hectares. (FAO, 2019)

The horn and the French plantain are believed to have similar origin, they are both grown in India, Africa and tropical America. Plantain relates closely to banana (*M. sapientum*). Plantain is an herb that grows up tot 3–10 metres. The leaf sheaths forms a conical false “trunk” arranged spirally. The fruits are usually larger than banana. The plantain's edible

fruit has more starch than a banana and should not be eaten uncooked. Plantains are usually boiled since they contain so much starch before they ripen. Plantain flour is typically made from unripe plantains, or ground for use as meals (Ukhum and Ukpebor, 1991), other west and central African countries. Plantain is a staple food and has been reported to be used in beer making in Eastern Uganda and Tanzania. The fruits are peeled by hand, the pulp is sliced into little bits, and the pulp is air dried for a few days (Momambo, 1993) before being crushed in a grinder or mortar. The flour is combined with hot water to make an elastic pastry that can be served with a variety of sauces. Due to the action of browning enzymes, the flour obtained has a more or less dark color. Plantain blanched for 5 minutes at 80°C and sliced into circular pieces improved this traditional procedure, followed by a few days of draining and drying in a oven at regulated temperature (Momambo, 1993).

2.18 Methods of Processing Plantain

Production of plantain is limited in Africa due to post-harvest loss resulting from unavailability of proper storage conditions that can enhance longer shelf life (Wills *et al*., 1989). Processing of plantains dried chips includes; harvesting, peeling, slicing and sun drying, then stored, it can also be ground to flour, poured into already boiled water to get an elastic paste (Amala in Nigeria and foufou in Cameroun). It is a seasonal crop which is highly abundant during the harvesting period and insufficient during its off-season periods, extremely perishable once it's been harvested, to avoid postharvest losses farmers process plantain to dried chips in order to boost the production of main food produce throughout the year, maintaining food security and generating a source of financial revenue for themselves during the off-season.

Plantains, grouped along with tubers constitute a whopping 22.60% of the total per food commodity expenditure profile for Nigerian households (NBS, 2010). This translates to an estimated 14.62% of the total per commodity expenditure profile for Nigerian homes (NBS, 2010). However, over 30% of produced crops in Nigeria are lost following harvest, due to poor storage facilities and lack of processing technology among others (Osagie and Eka, 1998). Sun-drying has long been a popular way to process and preserving plantains.

2.19. Organochlorine Pesticides

The use of insecticides is usually needed by farmers and marketer to reduce post harvest loss but they over-used, misused, or used unnecessarily because they have limited or no information on their application, their associated toxicity and implications on human health when it is found in food. As a result, pesticide residues or metabolites become adsorbent in the foods to which they are administered. Orkwor *et. al*. (1997) reported administration of pesticides like actellic, phostoxin, or a lindane/kerosene mixture with water on stored yam chips. Ogunfowokan *et al*. (2012), stated that lindane (Gammalin 20EC®) to be the most used insecticide by farmers in Nigeria, they mostly used it as aqueous solution for preventing insect pests and to formulate unauthorized local insecticides for general use. Exposure of human being to Pesticides can cause acute toxicity if consumed from contaminated food (Darko *et al*., 2008). organochlorine pesticides (OCPs) were commonly utilized in the preservation of food and storage of agricultural produce and have become one of the pesticides that are mostly found in the environment (Alle *et al*., 2009), they are very toxic, persistence and can travel fast in the atmosphere (Wang *et al.,* 2009). Organochlorine pesticides (OCPs) were prohibited in Nigeria but recent research has shown its presence in fish, soil, water, vegetable and food samples (Anzene *et al*., 2014; Oyo-Ita *et al*., 2014; Sosan *et al*., 2015).

2.20 Insects Pest of Dried Chips

The conversion of yam, potato, cassava and plantain into chips, after that, there's drying and storing for short or until when they are needed, subjected them to pests attack, which made security of food in Sub-Saharan Africa to be threatened.. The insect pests of dried chips are *Araecerus fasciculatus*, *Prostephanus truncatus*, *Dinoderus* spp, *Tribolium casteneum*, *Sitophilus zeamais*, *Sitophilus oryzae* (Agona, 1995). The Larger Grain Borer (LGB) (*P. truncatus*), which is endemic to Mexico and Central America, was introduced to Africa in the early 1980s. (Dustan and Magazini, 1981), (Agona, 1995). Of the pest complex, *A. fasciculatus* is the most important and its infestation is manifested by circular perforation of dried chips, reduce flour content, presence of frass, and cast skin of dead insects. (Agona, 1995).

2.21 Control of Insect Pest of dried chips

To reduce the damage levels of insect pest of sweet potato, farmers usually evaluate their crops on a regular basis and re-dry them in the sun. The results are usually negative, as the harm increases with time spent in storage. Insecticides are requested by farmers in response to the situation. There have been many reported methods of pest management for dried chips which include putting them in airtight containers, modifying of the different varieties (Pillai, 1977), salting chips before drying (Kumar and Karnavar, 1986), parboiling tubers before cutting and drying (Pillai and Rajamma, 1997). Focused solar energy has also been demonstrated as a successful method of insect pest control (Nakayama *et al.,* 1982).

2.22 Role of phytochemicals in Insect Control

Plant secondary metabolites defence plants from attack by a variety of microbes, insects, and herbivores. (Cowan, 1999). Phytochemical are chemical compounds produced by plants (Breslin, 2017*),* which gives them an edge against pathogens, competitors or predators. They are produced by primary or secondary metabolism (Molyneu *et al*., 2007, Harborne *et al*., 1999). Phytochemicals usually have biological functions in the host organism, such as development and protection against pathogens, parasites, and predators. (Molyneu *et al*., 2007). Phytochemicals was used as toxins, and the tropane alkaloids of Atropha belladonna have been utilized as poisons in traditional medicine, and ancient people created poisonous arrows from the plant (Michael, 1998) to stop the pathogens spread, plants utilizes inbuilt resistance as components of defense mechanisms. Many of these defenses are spontaneous, while others are induced in response to pathogen elicitors (Jones *et al.,* 2006), which included cell wall strengthening, secretion of secondary metabolites and protein based pathogenesis (Lindsay *et al*., 1993). Saponin have strong antimicrobial activities, which helps in the protection against potential pathogens (Osbourn, 2003). Alkaloids are prevalent in plant seeds and roots, and they are generally found in association with organic acids. (Madziga *et al*., 2010). Rattan (2010) listed alkaloids, terpenoids and phenolics as insecticidal secondary metabolites that occur in many plants with insecticidal properties.

Numerous compounds have been discovered in plants through phytochemical screening, such as saponins, glycosides, steroids, flavonoids, alkaloids, and tannins etc. Phytochemical consumption by human being helps in decreasing the risks involved in many kinds of diseases because of their ability to scavenge on free radical (Zhang *et al*., 2015). Humans are affected by some phytochemicals, which are known phytotoxins (Bjeldanes *et al*., 2009), Aristolochic acid, for example, is carcinogenic at small amount (Shaw, 2010). Many phytochemicals act as antinutrients, meaning they prevent nutrients from being absorbed (Oxford Dictionary, 2006). Some, like certain polyphenols and flavonoids, could be pro-oxidants when consumed in large quantities. (Halliwell, 2007). Phytochemicals present in botanical insecticides have been reported to contribute to their toxicity against arthropods (Babarinde *et al*., 2018).

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Site

The study was conducted at the Entomology Research Laboratory of the Department of Crop Protection and Environment Biology (CPEB), University of Ibadan. All experiments were carried out at temperature of 27±3^{o}C, 65±5% relative humidity and 12 hours photophase.

3.2 Sample collection and culture establishment

Selected food materials used in this study were dried chips of cassava, sweet potato, water yam, white yam, and plantain. The food materials used for the abundance study were obtained from fifteen different locations. Three markets were selected from each of the following selected states, Oyo, Osun, Ondo, Kwara and Ekiti, (Figure 3.1). A 10 kg infested sample of each dried chips of cassava, sweet potato, water yam, white yam, and plantain that have been infested were collected from the market and were taken to the Entomology Research Laboratory of the department of Crop production and Environmental Biology, University of Ibadan for culture establishment. In the laboratory, 200g samples of each infested dried chips collected were transferred into the 5 liters-size Kilner jars covered with mesh lids replicated 5 times. The cultures of *Araecerus fasciculatus* used for this study were established from the insects that emerged from the infested dried chips culture raised in the Laboratory.

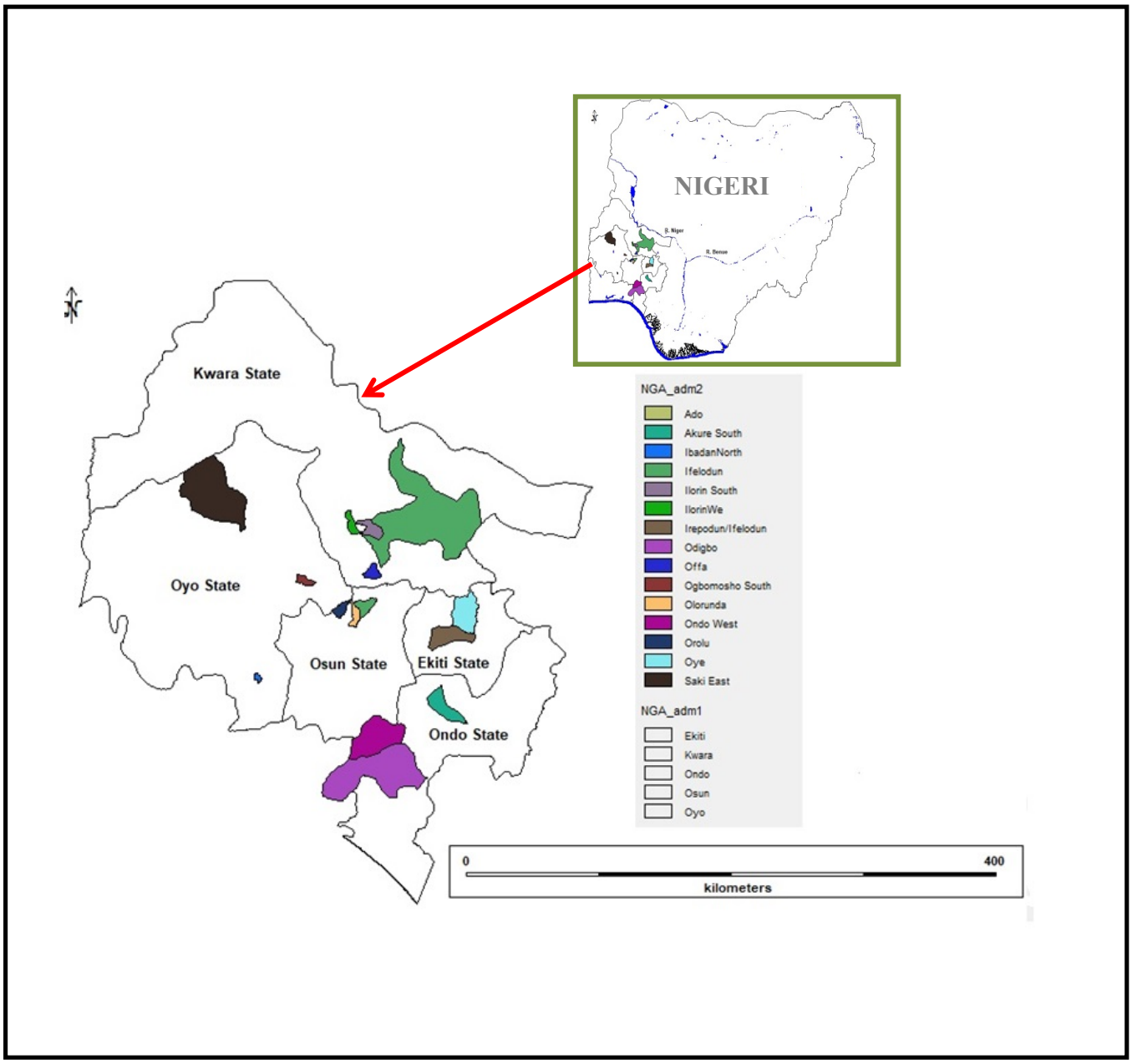


Fig 3.1: Map of State in south of River Niger with map of Nigeria inserted showing the study area where survey for *Araecerus fasciculatus* was conducted in 2016/2017

3.3 Survey of the abundance and diversity of insect species associated with some stored food crops in selected states in Nigeria

The study was carried out in fifteen markets in selected locations in Nigeria. Surveys were conducted during dry season (February to March) 2016 and 2017. The dried chips samples of cassava, sweet potato, water yam, white yam and plantain obtained from fifteen different markets in selected locations were used for the study (Fig 3.1). The dried chips were selected because they are the widely produced in those locations. Two-kilogram samples of each of cassava, sweet potato, water yam, white yam, and plantain dried chips were collected from fifteen different markets and were transported to Entomology Research Laboratory of the department of Crop production and Environmental Biology, University of Ibadan, colonies of insects were established and maintained following standard laboratory procedures. Each sample of dried chips collected was put in the 5 liters capacity rearing jars in the laboratory, it was replicated three times and arranged in Randomized Complete Block Design (RCBD), 27±3^{o}C, 65±5% relative humidity and 12 hours photo phase. Each food host constituted a treatment and was laid in four replicates. The experiment was daily observed to detect F_1 progenies emergence. Most abundant insects and other species of insect associated with each food host were assessed and recorded. Each replicate was observed daily for emergence and data were collected weekly on species of insects that emerged and number of emergent for 12weeks, insects were sorted according to species and identified by comparison with their type at the insects' museum reference centre of Department of CPEB, University of Ibadan.

Number and types of insects associated with each chip were evaluated by descriptive statistics of means and percentage and analysis of variance (ANOVA). Tukey's HSD test was used to differentiate means at the 5% level of significance ($P < 0.05$). Diversity indices were computed following the methods described by Magurran (2004) and Samways *et al.* (2010). The diversity indices computed were: number of species (Taxa), total number of individuals, Simpson index, Shannon diversity index, Pielou evenness index and Margalef's richness index. These diversity indices were calculated using Paleontological statistics, version 2.08. The Chao and Boot' and the Jacknife 1 indices

were used to estimate expected species richness, species composition and abundance following the improved procedure of Longino (1994) and Waongo *et al*., (2015). Insect species was classified based on their occurrence with Hierarchical Classification Analysis (HCA) and it was done using the Ward's and Euclidean distance method.

3.4 Determine the Organochlorine contamination of dried cassava and yam chips in selected locations in Nigeria

A 10kg sample of dried yam chips (*D. rotundata*) and cassava (*M. esculenta*) was obtained from open market in each of Ibadan (Bodija market, 7.44° N, 3.91° E), Shaki (Owode, 8.68° N, 3.39° E), Ilorin (Oja Oba, 8.49° N, 4.53° E) and Osogbo (Igbona, 7.78° N, 4.56° E) and Ikirun (Alamisi, 7.91° N, 4.66° E), and were kept in the open laboratory, arranged using RCBD. Thereafter, 10g was taken and analysed for Organochlorine residues following the method described by Environmental Protection Agency (EPA) method 8270D in United State in 2007 with slight modification. The samples were analyzed for Heptaclor, Aldrin, Endrin Aldehyde, Gamma-BHC, Delta-BHC, Beta-BHC, Heptaclor epoxide, Endosulfan I, p,p' – DDE, Alpha-BHC, Dieldrin, Endrin, p,p' – DDD, Endosulfan II, Endosulfan sulfate, Methoxychlor and p' – DDT. The collected sample were analysed for residual levels of Organochlorine pesticides using Agilent 7820a Gas Chromatography (GC), electron capture detector (ECD). Data collected were analyzed with descriptive statistics.

3.4.1 Sample Extraction

Three grammes (3 g) chip sample each was measured and ground in a mortal with Sodium Sulphate anhydrous (it was initially baked at 160^{o}C for 24 hours) thoroughly. The thoroughly grinded sample with Sodium Sulphate anhydrous was moved to the amber bottle for cold extraction with *n*-hexane (30 ml) for 6 hours on a platform shaker. The extract was refined to a concentration of about 2 to 5 ml with nitrogen evaporator.

3.4.2 Chromatographic Column Cleanup

To separate unwanted organic and polar species, column chromatography was employed. Briefly, a Silica gel column (250 mm x 25 mm) was filled from the ground up with

fiberglass, roughly 20 grams of active silica gel, and around 5 grams of sodium sulphate anhydrous to top it. Before loading the sample, the column was initially rinsed with 30 ml of n-hexane. The eluent (fraction) was rinsed in 30 ml of *n*-hexane to remove OCP. The eluted fraction was concentrated with the use of 2 ml nitrogen evaporator. The fraction was reconstituted with 1 ml Iso-octane in to a GC vial.

3.5 Comparative Biology *of Araecerus fasciculatus* on some Stored Dried Chips

The developmental and reproductive biology of *A. fasciculatus* were studied on cassava, sweet Potato, Water yam, White yam and Plantain following the method described by Ojo and Omoloye (2016).

3.5.1. Preparation of dried chips

The food crops used for this study were Cassava, sweet Potato, Water yam, White yam and Plantain. They were obtained from Bodija market, Ibadan. Traditional post-harvest processing was done to prepare dried chips. The food crops were peeled and cut manually with sharp stainless-steel kitchen knife into 3 x 1 x 1 cm sizes chips, they were cleaned properly to eliminate any dust, sand and dirt (Plate 3.1 and 3.2). Different processing methods were engaged in before drying, preparation of cassava was done followed the method described by Diop (1998), which involved soaking the cassava in water for 48h to reduce hydrogen cyanide present and for fermentation to occur, thereby spread in a perforated tray. Water Yam was drenched in liquid for 12h, White Yam and Potatoes were blanched in hot water (93 to 100^{o}C) for 2 minutes using the method of Shyam *et al.* (2006). Sliced plantain, water yam, fermented cassava and other blanched chips was later oven dried at 70^{o}C for five days till there was a uniform weight of each sample.

3.5.2 Life stages of *A. fasciculatus* on selected dry chips.

A 200g sample of each dry chip was weighed into 15cm diameter rearing jars in 4 replicates. The laboratory culture consisting of 20 unsexed adult *A. fasciculatus* were added to each jar adopting the method of Ojo and Omoloye (2016). Insects were removed after eight days of mating and oviposition to enable for *A. fasciculatus* egg and larval developmental studies on the dried chips. Number of egg laid was determined by using Acid fuchsin to stain the chips for easy identification and egg plug study on each chip and

Cassava

White yam

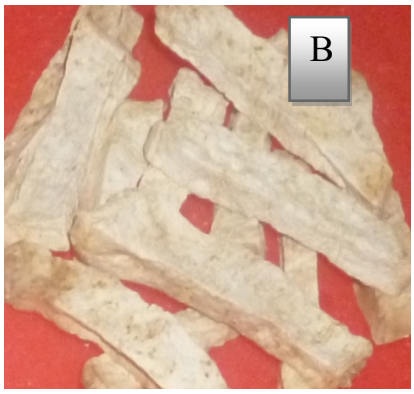
Sweet potato

Water yam

Plantain chips

Plate 3.1: Food materials (A-E) used for biological study and damage assessment of *Araecerus fasciculatus* in Nigeria

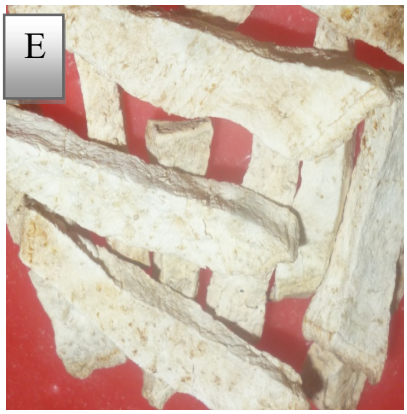
White yam chips



. Water yam chips

Plantain chips

Cassava chips



Sweet potato chips

Plate 3.2: Sliced chips of various root, tubers and crops and plantain after oven dried for biological study

to tracking of egg development. The acid fuchsin solution was made by mixing glacial acetic acid (250 ml), acid fuchsin (3.5 g) and distilled water (750 ml). The egg plug staining was assessed using Pedersen's (1979) techniques. Infested chips were dissected daily for vertex measurement with USB digital micr oscope (20X-400X) VI.8 Model. Inspections and measurements of larval instars were carried out on a daily basis till the pupa stage to determine the larval instars stages of *A. fasciculatus.* For fecundity and longevity study, 20g of each dried chips were weighed replicated 4 times, 5 pairs of *A. fasciculatus* were introduced into them. Every three days, the chips were changed, and the number of eggs laid was recorded, adult longevity was calculated only when all the *A. fasciculatus* display morbidity. Duration and larval vertex width were measured to determine larval instars stages. T-test was used to determine conformity of larval instar to Dyar's rule. Analysis of variance (ANOVA) and descriptive statistics were used to analyze the data, significant means were separated using the Tukey Honestly Significant Difference (Tukey HSD) test at 5% level of significance. Conformity of *A. fasciculatus* larval instars' growth rates to Dyar's rule was determined using a t-test. The head capsule widths of larval instars and instar duration relationship were determined using regression analysis.

3.5.3 Determination of Host Preference of of *Araecerus fasciculatus*

3.5.3.1 Preference and fertility study of *Araecerus fasciculatus* using free choice method

An improvised free – choice feeding compartments was made following a modified method of Ojo and Omoloye (2016) and Babarinde *et al.* (2008), 20 cm circle was made out of white cardboard paper. In the center of the cardboard, a 5cm radius circle was drawn with a pencil. The ring connecting the two circles was partitioned into five (5) equal compartments to form approximately 56cm^2 areas each. To restrict insects from escaping to the bottom of the cardboard at the container's base, the cardboard was put in the container and affixed to the bottom.

A 30g each of cassava, sweet potato, water yam, white yam and plantain was randomly introduced to each subdivision. Thirty (30) pairs of 2-day –old *A. fasciculatus* were

introduced into the 5 cm-radius inner circle and the container was covered with muslin cloth. The experiment was replicated thrice; data were taking number of insects migrated to different grains at 24, 48 and 72 hours after infestation. After 72 hours, each group was parked and incubated using 1- litre capacity kilner jars and left for a week under ambient conditions after which the weevils were removed from the kilner jars. The setup was kept untouched until F1 progeny emerged. The total amount and sex ratio of F1 progeny that emerged, as well as the period of development, were recorded. Data obtained were analysed using ANOVA and treatment means when significant were separated using Tukey HSD test at $\alpha = 0.05$.

3.5.3.2 Non-preference and fertility study of *Araecerus fasciculatus*

A 30 g each of the dried chips of cassava, sweet potato, water yam, white yam and plantain was kept in 2 litres capacity kilner jars. Ten pairs of 1-2 days old *A. fasciculatus* was introduced into them. They were left for a week under ambient condition of 27±3^{o}C, 65±5% relative humidity and 12 hours photophase and allowed to stay for 14 days after which they were removed, arranged in completely randomized design (CRD) replicated four times; chips were left undisturbed until F_1 generation has emerged. The total amount and sex ratio of F1 progeny that emerged, the length of development, and the weight loss of chips were all recorded and submitted for analysis of variance (ANOVA) and treatment mean when significant were separated using Tukey Honesty Significantly Difference (Tukey HSD) test at $\alpha = 0.05$. Determination of weight loss in percentage was calculated by subtracting infested (damaged) from uninfested (undamaged) chips as a fraction of the uninfested displayed in percentage.

$$WL = \left\{\frac{Wc - Wt}{Wc}\right\} x100$$

Where:

WL = weight loss in percentage

Wc = uninfested chips weight

Wt = infested chips weight

The body morphometry of the F_1 adult *A. fasciculatus* reared on different food host were determined. Twenty day old of each group of adult weevil species were randomly selected for morphometric studies. A binocular microscope with a graticle in one eyepiece and USB digital microscope (20X-400X) VI.8 Model were used. The morphological features measures were length (mm) of the body and width (mm) of the body and weight (mg). Data obtained were analysed using ANOVA and treatment means when significant were separated using Tukey HSD test at $\alpha = 0.05$.

3.6 Assessment of qualitative and quantitative damage by *Araecerus fasciculatus* on selected dried chips.

Dried chips were prepared with the same procedure as in 3.2 above. Two sets of 200g sample of each dried chips materials were placed in 2 litres capacity Kilner jars, which were covered with muslin cloth for aeration and to stop other pests from infesting them. In the first set, twenty-day old adult *A. fasciculatus* were introduced into the Kilner jars and the sets up arranged in the laboratory using a CRD. The second sets up were left uninfested to serve as control. The experiment was replicated four times. The set up were reweighed at 30, 60 and 90 days after infestation. Determination of weight loss in percentage was calculated by subtracting infested (damaged) from uninfested (undamaged) chips as a fraction of the uninfested displayed in percentage.

$$WL = \left\{\frac{Wc - Wt}{Wc}\right\} x100$$

Where:

WL = weight loss in percentage

Wc = uninfested chips weight

Wt = infested chips weight

The powdery waste on the quantitative damage were analyzed for mineral element, using the established techniques by the Association of Official Analytical Chemists (2005). Data collected on weight loss, frass weight, and mineral element and proximate analyses data obtained were analysed using ANOVA and treatment means when significant were separated using Tukey HSD test at $\alpha = 0.05$.. The frass amount generated by the *A.*

fasciculatus was measured after 90 days of infestation on all the samples by emptying each jar of all insects as all the samples were emptied into trays, sieved to remove the powder from the infested chips. The powders that pass through the sieve are known as insect frass, the frass collected was then weighed. The procedures were repeated for all replicates.

3.7 Analysis of infested and non-infested samples for proximate and mineral analysis

Infested (damaged) and non infested (Undamaged) samples were analyzed for mineral element and proximate analyses, the established techniques by the Association of Official Analytical Chemists (2005) was used.

3.7.1. Determination of Crude Protein (A.O.A.C. Official Method 2005)

Determination of crude protein in cassava, potato, wateryam, white yam and plantain were determined by using the procedure of the routine semi-micro Kjeldahl (AOAC Official Method, 2005). The steps involved are Digestion, Distillation and Titration.

(i) Reagents: 40% (W/V) NaOH, Kjeldahl Catalyst tablet, 2% Boric Acid Solution, ConC.H_2SO_4, 0.01NHCl, Methyl Red – Bromocresol green mixed indicator.

(ii) Digestion: 0.5g of each powder of dried chips sample of cassava, potato, wateryam, white yam and plantain were weighed into Kjeldahl digestion tubes, 10ml of ConC. H_2SO_4 and 1 Kjeldahl catalyst tablet were added and carefully ensured that all the chips samples reached the bottom of the tubes. Samples was replicated three times and carefully arranged in the Digestion Block Heaters for 4 hours, until when a clear and clean solution without any colour was obtained. It was left to cool and later emptied into 100ml capacity volumetric flask.

(iii) Distillation: Markham Distillation Apparatus was used for the distillation; the samples were steamed for ten minutes. To extract condensed water, the steam generator was disconnected from the source of heat and connected to the full developing vacuum. 5 ml portion of the already digested samples were poured

with small funnel opening into the apparatus body, 5ml of 40% (W/V) NaOH was added, mixed and heat for 2 minutes into a 50ml conical flask and add 10ml of 2% Boric Acid plus blended indicator solution, then put at the condenser's receiving tip. Boric Acid colour with the solution turned green, indicating trapping of all the liberated ammonia.

(iv) Titration: A 50ml Burette was used to titrate the resulting green color solution against 0.01N HCl. The green color changes to wine in the end, indicating that all of the Nitrogen held as Ammonium Borate [$(NH_4)_2BO_3$] has been released as Ammonium Chloride. (NH_4Cl).

The nitrogen percentage was estimated as:

$$\%N = \frac{\text{Titre Value} \times \text{Normality}}{\text{Molarity of HCL} \times \text{Atomic mass of N} \times \text{Vol. of flask containing the digest}} \times \frac{100}{1}$$

For steam distillation, multiply the sample weight digested in milligrams by the volume of the digest, content of the crude protein is calculated by multiplication of nitrogen percentage by a fixed factor of 6.25 i.e. % CP = % N x 6.25.

3.7.2 Determination of Crude Fat

(i) Apparatus: Analytical balance, Soxhlet apparatus, oven and desiccators.

(ii) Reagents: Petroleum spirit or Ether (40° – 60°C b.pt).

Dried sample (1 gram each) of cassava, potato, wateryam, white yam and plantains were weighed and softly pugged with cotton wool in a fat-free extraction thimble. Inside the extractor the thimble was put and equipped with a reflux condenser and a 250 ml soxhlet flask that had been oven dried, chilled in the desiccators and weigh again. After that, Petroleum ether (b.pt.40^o–60^{o}C) was added to the soxhlet flask to fill it to ¾ content. The condenser and extractor were heated. The Ether is allowed to siphon for times, 10 –12 times, until it runs out. The thimble carrying the material is then withdrawn and it was dried on the kitchen worktop using a mirror glass. The condenser, extractor and flask, and are all changed, distillation process proceeds till when the flask is almost completely dry.

The container that holds the fat is removed, cleaned, and oven dried. The initial weight of the dry soxhlet flask is Wo, and the final weight of the oven dried is W_1, the percentage fat can be calculated using the formula:

$$= \frac{W_1 - W_0}{Wt.of\ sample\ taken} \times \frac{100}{1}$$

3.7.3 Dry Matter and Moisture Determination

A 2g of the sample of cassava, potato, water yam, white yam and plantain were measured into a crucible. The crucible, together with the sample collected, was then oven dry to a consistent weight, set at 1000°C for 24 hours. The sample and crucible were brought out of the oven after 24 hours and placed in desiccators to cool for 10 minutes before being weighed.

Empty crucible weight is Wo

Crucible weight plus sample is W_1

Crucible weight plus oven-dried sample W_3

$$\%\ \text{Dry Matter} = \frac{W_3 - W_0}{W_1 - W_0} \times \frac{100}{1}$$

$$\%\ \text{Moisture} = \frac{W_1 - W_3}{W_1 - W_0} \times \frac{100}{1}$$

3.7.4 Ash Content Determination

A 2 g sample was placed in a ceramic crucible and put in the muffle furnace, which was heated to 550°C, and left for 4 hours. It was changed to ash white. The content in the crucible and its components were weighed after cooling to about 100°C. This was carried out twice. The ash percentage was determined as following:

$$\text{Ash Content} = \frac{Wt.of\ Ash}{Original\ Wt.of\ sample} \times \frac{100}{1}$$

3.7.5 Fibre Content Determination

In the fibre flask, 2g of the material was properly weighed, and was added 100ml of 0.255N H_2SO_4. With the heating mantle, it was heated for 1 hour under reflux. The heated mixture was filtered using a fibre filter cloth. The filterate was discarded, and the remaining was returned to the fibre flask, which was then filled with 100ml of (0.313N NaOH) and heated for one hour under reflux. To dissolve any organic constituents, 10ml acetone was administered after the solution was sieved using a fibre filter cloth. Before being put into a crucible, it was rinsed with 50ml hot water using the filter. To remove moisture, both the residue and crucible were oven-dried overnight at 105°C. The weight was determined by using a dessicator to cool the dried crucible with the residue and then weighing it (W_1). It was later placed in the muffle furnace for 4 hours at 550°C for ashing. In the desiccators, a crucible holding white or grey ash was cooled and weighted (W_2). The fibre weight is the subtraction between $W_1 - W_2$.

The fibre % was estimated as:

$$\% \text{ Fibre} = \frac{W_1 - W_2}{Wt.of\ sample} \times \frac{100}{1}$$

3.7.6 Calcium and Potassium Determination

Each sample's of the ash in the crucible was digested by mixing 5ml of 2 M HCL to it and drying it on a heater. To the mixture was 5ml of 2 MHCL was poured again, brought to a boil, and filtered into a 100ml volumetric flask through a Whatman No. 1 filter paper. The filtrate was prepared up to the mark with distilled water stoppered and set aside for reading calcium and potassium concentrations on the Jenway Digital Flame Photometer (PFP7 Model) with the appropriate filter for each mineral element. The concentrations of each element were determined using the formula:

$$\% \text{ Ca} = \frac{\text{Meter Reading (MR) x Slope x Dilution factor}}{1000}$$

$$\% \text{ K} = \frac{\text{Meter Reading (MR) x Slope x Dilution factor}}{1000}$$

3.7.7 Phosphorus Determination (Spectrophotometric method):

The ash from each of the samples was added an HCL solution as indicated above for calcium assessment. 10 mL filterate was poured into a 50 mL standard flask, 10 mL vanadate yellow solution was added, distilled water was used to fill flask and allowed to stay for 10 minutes for total yellow colour. The quantity of phosphorus was determined using a Spectronic 20 spectrophotometer or colorimeter at a wavelength of 470 nm to measure the optical density (OD) or absorbance of the solution.
Using the formula, the proportion of phosphorus was calculated:

$$\% \text{ Phosphorus} = \frac{\text{Absorbance x Slope x Dilution factor}}{1000}$$

3.7.8 Determination Iron (Fe) using buck 200 AAS:

The iron ash digest was rinsed and was marked in a 100ml volumetric flask with distilled water. Through the suction tube, this diluent was sucked into the Buck 200 Atomic Absorption Spectrophotometer (AAS). It was later read at its wavelengths with hollow cathode lamps applying the proper fuel and oxidant mixture

3.8. Efficacy of processing dried chips with Fermented maize water and lime

The different concentration of the treatments was presented in Table 3.1

3.8.1. Preparation of Fermented Maize Water.

A 10kg Maize sample was obtained from Bodija Ibadan, washed thoroughly and soaked in cold water for three days for the process of fermentation, thereafter, ground to form a paste. The paste obtained was mixed with water and sieved by using a musilin cloth to remove big particles. The sieved maize paste was left for 48hours to decant. Fermented maize water was separated after 48 hours and was used for further study.

Table 3.1: Treatment application rate

S/N	Chips (1kg)		FMW (ml)		Water (ml)		Lime Juice(ml)		Description (Treatments)
1	Cassava	+	250.0	+	747.5	+	2.5	Treatment 1	T_1
2	Cassava	+	250.0	+	745.0	+	5.0	Treatment 2	T_2
3	Cassava	+	250.0	+	742.5	+	7.5	Treatment 3	T_3
4	Cassava	+	250.0	+	740.0	+	10.0	Treatment 4	T_4
5	Cassava	+	250.0	+	750.0	+	0.0	Control	T_5
6	Cassava	+	0.0	+	1000.0	+	0.0	Control	T_6
7	Potato	+	250.0	+	747.5	+	2.5	Treatment 1	T_1
8	Potato	+	250.0	+	745.0	+	5.0	Treatment 2	T_2
9	Potato	+	250.0	+	742.5	+	7.5	Treatment 3	T_3
10	Potato	+	250.0	+	740.0	+	10.0	Treatment 4	T_4
11	Potato	+	250.0	+	750.0	+	0.0	Control	T_5
12	Potato	+	0.0	+	1000.0	+	0.0	Control	T_6
13	Water yam	+	250.0	+	747.5	+	2.5	Treatment 1	T_1
14	Water yam	+	250.0	+	745.0	+	5.0	Treatment 2	T_2
15	Water yam	+	250.0	+	742.5	+	7.5	Treatment 3	T_3
16	Water yam	+	250.0	+	740.0	+	10.0	Treatment 4	T_4
17	Water yam	+	250.0	+	750.0	+	0.0	Control	T_5
18	Water yam	+	0.0	+	1000.0	+	0.0	Control	T_6
19	White yam	+	250.0	+	747.5	+	2.5	Treatment 1	T_1
20	White yam	+	250.0	+	745.0	+	5.0	Treatment 2	T_2
21	White yam	+	250.0	+	742.5	+	7.5	Treatment 3	T_3
22	White yam	+	250.0	+	740.0	+	10.0	Treatment 4	T_4
23	White yam	+	250.0	+	750.0	+	0.0	Control	T_5
24	White yam	+	0.0	+	1000.0	+	0.0	Control	T_6
25	Plantain	+	250.0	+	747.5	+	2.5	Treatment 1	T_1
26	Plantain	+	250.0	+	745.0	+	5.0	Treatment 2	T_2
27	Plantain	+	250.0	+	742.5	+	7.5	Treatment 3	T_3
28	Plantain	+	250.0	+	740.0	+	10.0	Treatment 4	T_4
29	Plantain	+	250.0	+	750.0	+	0.0	Control	T_5
30	Plantain	+	0.0	+	1000.0	+	0.0	Control	T_6

FMW- Fermented maize water

Source: Prepared treatments used for the study

3.8.2. Preparation of Lime Juice

A 5kg sample of matured lime fruits were obtained from Bodija market Ibadan was washed thoroughly with clean water to remove dirt. They were then sliced into two to squeeze out the juice. It was stored in refrigerator in the Entomology laboratory before use.

3.8.3. Preparation of dried chips

The food crops used for this study were Cassava, Potato, Water yam, White yam and Plantain. They were obtained from Bodija market Ibadan. The food Crops were hand peeled using a sharp stainless-steel kitchen knife and chopped into 3 x 1 x 1 cm and washed thoroughly to remove all mud, dirt, and sand. Each sliced chip was batched into lot of 1kg and prior to drying, they were subjected to various processing systems. Cassava was first soaked inside water for 48 hours (FAO, 2008) and after blanching for 2 minutes at (100^{o}C) using water, lime and fermented maize water at different ratio (Table 3.1) with continuous stirring of the mixture. Water yam, White yam potato and plantain passed through the same processing of blanching without prior soaking inside water. Each treated chip was later spread on perforated tray oven dried at 70^{o}C for some days till uniform moisture content was reached.

3.8.4 Efficacy of the treatment on the developmental period and adult longevity of *A. fasciculatus* on different dried chips.

A 200g samples of each treatment prepared and weighed with a sensitive balance scale (Gibertini TM 1600®, Italy) and placed in rearing jars, each treatment was replicated 4 times, 10 pairs of *Araecerus fasciculatus* were introduced to them to feed and oviposit, the control was an insect-free rearing jar, the rearing jars were covered with muslin cloth to provide for aeration and to keep other pests out. The set up was arranged in CRD in the laboratory and monitored for days. Data were collected on their development from egg to adult on each chips, longevity of the adult was determined when all the *A. fasciculatus* showed morbidity. Data obtained were analysed using ANOVA and descriptive statistics, treated means when significant were separated using Tukey HSD test at $\alpha = 0.05$.

3.8.5 Efficacy of the treatment on the damage of *A. fasciculatus* on different dried chips.

Two sets of 200g sample of each treated dried chips were placed in 2L capacity Kilner jar, the rearing jars were covered with muslin cloth to provide for aeration and to keep other pests out. In the first set, twenty-day old adult of *A. fasciculatus* were introduced into the Kilner jars and the set up arranged in the laboratory using a CRD. The second set was left uninfested to serve as control. The experiment was replicated four times. The set up was left for 90 days and reweighed. Determination of weight loss in percentage was calculated by subtracting infested (damaged) from uninfested (undamaged) chips as a fraction of the uninfested displayed in percentage.

$$WL = \left\{\frac{Wc - Wt}{Wc}\right\} x100$$

Where:

WL = percentage weight loss

Wc =weight of uninfested sample

Wt =weight of infested sample

Data on weight loss were analysed using ANOVA and treatment means when significant were separated using Tukey HSD test at $\alpha = 0.05$.

3.8.6. Determination of quantitative phytochemical content of the treated samples

3.8.6.1. Determination of Tannin

In a 50ml beaker, 0.20g of sample was measured, to it was added 20mL of 50% methanol, wrapped in parafilm, and put in a 77-80°C water bath for 1 hour. To achieve consistent mixing, it was shaken thoroughly. The extract was quantitatively filtered into a 100ml volumetric flask using a double-layered Whatman No 11-filter paper, 20ml water, 2.5ml folin-Denis reagent, and 10ml of 17 percent Na_2CO_3 were added and carefully mixed. The mixture was prepared up to the mark with water and let to stand for 20 minutes, during

which time the bluish-green color developed after 20min Working standard solutions of Tannin of range 0-10ppm were treated similarly as 1ml sample above. The absorbance of Tannic acid and samples was recorded using a Spectronic 21D spectrophotometer at 760nm after color development (A.O.A.C. 1984). The formula for calculating percent Tannin was used as:

$$\% \text{ Tanin} = \frac{\text{Absorbance of sample x Average gradient factor x Dilution factor}}{\textit{Wt. of sample X } 10{,}000}$$

3.8.6.2 Determination of Alkaloids

Titrimetric method and distillation: To make a smooth paste, in a 100ml beaker, the 2g powdery sample was measured and 20mls of 80 percent pure alcohol were poured. It was moved to a 250ml flask, poured additional alcohol to bring the total volume to 100ml, as well as 1g magnesium oxide. It was digested for 90 minutes in a hot water bath with occasional shaking. A tiny buchner funnel was used to filter the mixture while it was still hot. It was reintroduced to the flask and digested for 30 minutes with 50ml alcohol before being drained and replaced with hot water. After removing all of the alcohol, 10% HCl (3 drops) was added. After that, the entire mixture was put into a 250ml volumetric flask. 5 mL zinc acetate solution and 5 mL potassium ferrocyanide solution were combined thoroughly to form a homogeneous solution (Henry, 1993).

The flask was left to rest for a a while before being sieved with a filter paper and 10ml of the filtrate was put into a separating funnel, where the alkaloids in the solution were aggressively obtained by shaking with five different amounts of chloroform. It was diluted in 10ml hot distilled water and moved to a kjeldahl tube with 0.20g sucrose, 10ml Conc.H_2SO_4 and 0.02g selenium for digestion to a colorless solution using the Kjeldahl distillation method to estimate percent N. By multiplying by 3.26, percent nitrogen was converted to percent total alkaloid i.e

% Alkaloids = %N X 3.26

3.8.6.3 Determination of Saponin

Saponin analysis was performed using Brunner (1984) Spectrophotometric technique. In a 250ml beaker, 1g of dried sample was weighed and to it was added isobutyl alcohol (100ml). To achieve equal mixture, the slurry was shook for 5 hours using a UDY shaker. The whole mixture was then sieved into a 100ml beaker, 20ml of a 40 percent $MgCO_3$ solution was added. The saturated $MgCO_3$ solution was filtered again to achieve a colorless solution. 1 mL of the colourless solution was put in a volumetric flask of 50 mL capacity, followed by 2 mL of 5% $FeCl_3$ solution and distilled water to make up to the mark. It was let to stand for 30 minutes to acquire a blood red tint. Saponin stock solution was used to make 0-10ppm standard Saponin solutions. The standard solutions were prepared in the same way as the 1ml sample above, with 2ml of 5% $FeCl_3$ solution. After color development, the absorbance of the sample as well as standard saponin solutions was measured in a Jenway V6300 Spectrophotometer at a wavelength of 380min (Brunner, 1984).

$$\% \text{ Saponin} = \frac{\text{Absorbance of sample x gradient factor x Dilution factor}}{Wt.of\ sample\ X\ 10{,}000}$$

3.8.6.4 Determination of Phenol

To avoid lumping, 0.20g of material was weighed into a beaker, of which 20ml acetone was mixed, the mixture was homogenized adequately for 1 hour. The mixture was filtered through into a 100ml Volumetric Flask, rinsed with acetone, and added distilled water to made up to the mark, allowed to mixed thoroughly. 1 mL of sample put into a 50 mL volumetric flask, 20 mL of water and 3 mL of phosphomolybdic acid was added, followed by 5 mL of 23 % $NaCO_3$ and distilled water which was thoroughly mixed and allowed to stand for 10 minutes to acquire a bluish-green color. A Digital Spectrophotometer was used to measure the absorbance of the sample and also that of standard Phenol concentrations at a wavelength of 510nm. The formula is used to compute the percentage of phenol

$$\% \text{ Phenol} = \frac{\text{Absorbance of sample x gradient factor x Dilution factor}}{Wt.\,of\ sample\ X\ 10{,}000}$$

3.8.7. Influence of Treatment on Organoleptic Properties of Selected Dried Chips (Amala)

Organoleptic test was examined on the treated chips to determine the taste, colour, odour, elasticity, viscosity, smoothness, stickness and the acceptability of the treated chips. The evaluation was conducted with 45 tasters (Staff and Students of Crop Protection and Environmental Biology, University of Ibadan, Ibadan Nigeria). All samples were served inside small disposable container, replicated three times, making 90 samples. Two samples were giving to each taster, a coded digit numbers were labeled on them and all the tasters received samples at the same time. A 7-point rating scale was adopted from Weireko-manu *et al* (2013) with a little modification, where 1 = very poor, 2 = moderately poor, 3 = slightly poor, 4 = Moderate, 5 = moderately better, 6 = much better, 7 = extremely good. All tasters assessment data obtained were analysed using ANOVA and descriptive statistics, treated means when significant were separated using Tukey HSD test at $\alpha = 0.05$.

CHAPTER FOUR

RESULT

4.1. Occurrence and status of insects species found on the selected dried chips

The occurrence of insects associated with the dried chips in selected locations in Nigeria are shown in Table 4.1. Ten species of insects were found during the survey comprising of *Sitophilus zeamais, Tribolium castaneum, Araecerus fasciculatus, Dinoderus minutus, Rhyzopertha dominica, Prostephanus truncatus, Callosobruchus maculatus, Lasioderma serricorne, Theocolax elegans, Cephalonomia waterstoni*. They belong to eight families: Curculionidae, Bostrichidae, Tenebrionidae, Anobiidae, Pteromalidae, Chrysomelidae, Anthribidae and Bethylidae, in two orders, Coleoptera and Hymenoptera. The Coleopteran species were all pests; while the Hymenopteran species were parasitic wasps parasitizing on pests of the dried chips. There were eight coleopteran species comprising *Sitophilus zeamais, Tribolium castaneum, Araecerus fasciculatus, Dinoderus minutus, Rhyzopertha dominica, Prostephanus truncatus, Callosobruchus maculatus, Lasioderma serricorne, and* two *hymenopterans* were *Theocolax elegans, Cephalonomia waterstoni*. The parasitic wasps were natural enemies of the insect pests associated with the dried chips studied. All the insects observed were polyphagous because they were found on two or more of the dried chips studied.

Identified pests were grouped into primary and secondary pests, and natural enemies of pests (Table 4.1). There was a total of five primary pests and three secondary pests, and two natural enemies. The highest occurring pest was *Araecerus fasciculatus* and *Dinoderus minutus* which were found in all the dried chips: cassava, potato, water yam,

Table 4.1: Occurrence of insects associated with all the food hosts in 2016/2017 in selected locations

S/n	Taxon	Common Name	Order	Family	Host	Pest status
1	*Sitophilus zeamais* Motschulsky	Maize weevil	Coleoptera	Curculionidae	Cassava, Potato, Plantain	Primary
2	*Tribolium castaneum* (Herbst)	Red flour beetle	Coleoptera	Tenebrionidae	Cassava Plantain	Secondary
3	*Araecerus fasciculatus* (De Geer)	Coffee bean weevil	Coleoptera	Anthribidae	Cassava, Potato, Water yam, White yam, Plantain	Primary
4	*Dinoderus minutus* (Fabricius)	Bamboo powderpost beetle	Coleoptera	Bostrichidae	Cassava, Potato, White Yam, Water yam, Plantain	Primary
5	*Rhyzopertha dominica* (Fabricius)	Lesser grain borer	Coleoptera	Bostrichidae	Cassava, Potato, Water yam, White yam	Primary
6	*Prostephanus truncatus* (Horn)	Larger grain borer	Coleoptera	Bostrichidae	Cassava, Potato, Water yam, White yam	Primary
7	*Callosobruchus maculatus* (Fabricius)	Cowpea weevil	Coleoptera	Chrysomelidae	Cassava, Potato Water yam, White yam,	Secondary
8	*Lasioderma serricorne* (Fabricius)	Cigarette beetle	Coleoptera	Anobiidae	Potato, Water yam, White yam.	Secondary
9	*Theocolax elegans* (Westwood)	Parasitoid wasp	Hymenoptera	Pteromalidae	Cassava, Water Yam, White Yam	Natural enemy
10	*Cephalonomia waterstoni* Gahan	Parasitic grain wasp	Hymenoptera	Bethylidae	Water Yam, White Yam	Natural enemy

white yam and plantain. *Rhyzopertha dominica, Prostephanus truncatus* and *Callosobruchus maculatus* were observed in four dried chips: cassava, potato, water yam and white yam. *Sitophilus zeamais, T. elegans* and *L. serricorne* were presents in three of the food hosts, the least occurrence was recorded for *T. castaneum* and *C. waterstoni* which associated with two food hosts.

4.2 Abundance of insect species associated with the selected dried chips

The abundance of insect species associated with cassava significantly ($P < 0.05$) varied across the selected locations in Nigeria (Table 4.2). *Tribolium castaneum* and *S. zeamais* were two most abundant insects on cassava chips across the selected locations. Their populations were different significantly from other insect species populations (Table 4.2). The lowest insect species across the selected locations were *R. dominica* and *D. minutus* (Table 4.2). The abundance of insects associated with potato significantly varied across the selected locations (Table 4.3). *Prostephanus truncatus* (32.33 ± 3.42) was the most abundant insect on potato across the selected locations. Its populations were greater significantly than other insect's species populations (Table 4.3). *Rhyzopertha dominica* and *L. serricorne* have the same level significance but significantly higher than other insect species counted. The least abundant species across the selected locations were *S. zeamais and A. fasciculatus* (Table 4.3).

However, the most abundant insect species associated with water yam: *Araecerus fasciculatus* was higher significantly than the population of *R. dominica* and *P. truncatus* across the selected locations (Table 4.4). The abundance of *C. maculatus* and *T. elegans* have the same level of significance but greater significantly than *D. minutus* (11.00 ± 2.01) which had the lowest abundance of insect species (Table 4.4). The abundance of insect's species associated with white yam significantly varied across the selected states of Southwest Nigeria (Table 4.5). The most abundant insects observed across the selected locations was *Araecerus fasciculatus* (77.67 ± 4.00), with populations that was higher significantly from other insect's species populations found. The abundance of *C. maculatus* and *C. waterstoni* were not higher significantly than the population of *L. serricorne.* The least abundant insects on white yam were *P. truncatus*.

Table 4. 2: Abundance (Mean ± SE) of insects associated with dried cassava chips in 2016/2017 in selected locations in Nigeria

Insects	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Sitopihilus zeamais	42.67±	31.78±	57.44±	35.33±	7.44±	10.22±	21.11±	14.56±	49.33±	43.89±
	6.61^{a}	1.23^{bc}	3.52^{a}	2.51^{a}	7.44^{b}	5.43^{ab}	4.24^{b}	1.63^{a}	8.90^{a}	4.62^{a}
Tribolium castaneum	52.89±	44.56±	51.11±	34.33±	45.56±	34.00±	40.33±	29.11±	15.00±	29.67±
	5.04^{a}	3.53^{b}	3.82^{a}	2.63^{a}	5.32^{a}	3.91^{a}	6.43^{a}	2.11^{a}	8.71^{bc}	6.92^{ab}
Araecerus fasciculatus	5.00±	75.44±	0.00±	22.44±	40.33±	24.67±	37.67±	14.33±	16.8±	4.44±
	5.03^{cd}	7.13^{a}	0.00	4.32^{a}	6.71^{a}	2.92^{a}	5.53^{ab}	2.00^{a}	2.71^{ab}	3.23^{de}
Dinoderus minutus	0.00±	33.89±	0.00±	11.11±	0.00±	17.78±	0.00±	12.22±	0.00±	12.56±
	0.00^{d}	4.62^{bc}	0.00^{c}	3.12^{ab}	0.00^{b}	1.42^{a}	0.00^{c}	6.53^{ab}	0.00^{c}	3.13^{bcd}
Ryzopertha *dominica*	4.89±	22.33±	0.00±	7.89±	0.00±	14.67±	0.00±	11.22±	0.00±	13.22±
	1.33^{cd}	6.24^{cd}	0.00^{c}	7.92^{ab}	0.00^{b}	7.44^{ab}	0.00^{c}	7.42^{ab}	0.00^{c}	2.94^{bcd}
Prostephanus truncatus	27.33±	34.00±	34.00±	15.56±	0.00±	21.22±	26.78±	22.22±	22.00±	20.11±
	1.42^{ab}	1.53^{bc}	4.82^{ab}	8.90^{ab}	0.00^{b}	4.72^{a}	1.93^{ab}	1.42^{a}	0.54^{ab}	0.82^{bc}
Callosobruchus maculatus	0.00±	26.00±	0.00±	18.67±	0.00±	24.11±	0.00±	9.33±	0.00±	26.56±
	0.00^{c}	1.71^{bc}	0.00^{c}	0.52^{ab}	0.00^{b}	1.80^{a}	0.00^{c}	0.53^{ab}	0.00^{c}	0.71^{abc}
Theocolax elegans	15.00±	9.00±	18.33±	8.67±	26.00±	0.00±	24.33±	15.00±	12.67±	10.67±
	3.62^{bc}	0.64^{d}	8.92^{b}	4.52^{ab}	4.51^{ab}	0.00^{b}	3.54^{ab}	3.00^{a}	3.72^{bc}	0.91^{cd}
Coefficient of variation (%)	22.5	11.0	19.1	36.8	31.9	30.2	14.7	30.3	31.6	17.8

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Table 4.3: Abundance (mean ± SE) of insects associated with sweet potato in 2016/2017 in selected locations in Nigeria

Insects	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Sitophilus zeamais	13.78± 3.20[a]	15.00± 3.90[a]	0.00± 0.00[b]	10.56± 0.90[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[c]
Araecerus fasciculatus	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[c]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	13.78± 4.71[a]	0.00± 0.00[c]
Rhyzopertha dominica	21.00± 6.20[a]	14.00± 6.72[a]	31.67± 19.21[a]	0.00± 0.00[c]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	6.44± 0.73[a]	0.00± 0.00[c]
Prostephanus truncatus	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[b]	0.00± 0.00[c]	32.33± 3.42[a]	17.00± 0.84[a]	25.11± 7.32[a]	15.89± 0.91[a]	0.00± 0.00[b]	8.89± 0.60[b]
Lasioderma serricorne	0.00± 0.00[b]	8.00± 0.82[a]	0.00± 0.00[b]	24.22± 1.43[a]	0.00± 0.0[b]	16.67± 0.70[a]	0.00± 0.00[b]	8..89± 0.81[b]	0.00± 0.00[b]	28.44± 0.62[a]
Coefficient of Variation (%)	29.86	18.68	8.04	7.61	13.34	4.75	34.09	7.08	28.79	4.08

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Table 4.4: Abundance (mean ± SE) of insects associated with water yam in 2016/2017 in selected locations in Nigeria

Insects	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Araecerus fasciculatus	61.89± 4.92^{a}	68.11± 7.72^{a}	93.22± 3.41^{a}	83.56± 6.90^{a}	87.51± 3.13^{a}	74.44± 7.12^{a}	84.33± 1.82^{a}	74.22± 6.54^{a}	51.00± 3.44^{a}	57.67± 7.81^{a}
Dinoderus minutus	0.00± 0.00^{c}	11.00± 2.01^{d}	0.00± 0.00^{c}	11.44± 2.14^{cd}	0.00± 0.00^{d}	0.00± 0.00^{d}	0.00± 0.00^{c}	0.00± 0.00^{e}	0.00± 0.00^{b}	0.00± 0.00^{d}
Rhyzopertha dominica	15.78± 5.82^{b}	30.67± 3.51^{b}	0.00± 0.00^{c}	36.00± 3.73^{b}	0.00± 0.00^{d}	31.44± 1.33^{b}	0.00± 0.00^{c}	37.00± 4.82^{b}	0.00± 0.00^{b}	27.44± 3.42^{b}
Prostephanus truncatus	15.56± 0.44^{b}	14.67± 1.72^{cd}	13.56± 1.32^{b}	17.56± 2.41^{c}	30.56± 0.40^{b}	22.67± 1.22^{b}	0.00± 0.00^{c}	10.00± 1.30^{cd}	0.00± 0.00^{b}	0.00± 0.00^{d}
Callosobruchus maculatus	0.00± 0.00^{c}	24.44± 0.10^{bc}	0.00± 0.00^{c}	5.78± 0.92^{d}	0.00± 0.00^{d}	4.22± 0.51^{c}	0.00± 0.00^{c}	18.22± 1.52^{c}	0.00± 0.00^{b}	18.33± 2.70^{bc}
Lasioderma serricorne	0.00± 0.00^{c}	24.56± 0.90^{bc}	0.00± 0.00^{c}	5.78± 0.83^{d}	0.00± 0.00^{d}	4.44± 2.42^{cd}	0.00± 0.00^{c}	0.00± 0.00^{e}	0.00± 0.00^{b}	15.67± 0.82^{c}
Theocolax elegans	9.00± 1.00^{b}	11.33± 1.21^{cd}	13.33± 0.93^{b}	0.00± 0.00^{e}	10.33± 3.81^{c}	8.67± 0.32^{c}	10.00± 1.52^{b}	9.00± 1.51^{d}	0.00± 0.00^{b}	0.00± 0.00^{d}
Cephalonomia waterstoni	14.67± 3.72^{b}	12.00± 3.71^{d}	14.33± 1.93^{b}	0.00± 0.00^{e}	10.33± 1.91^{c}	0.00± 0.00^{d}	0.00± 0.00^{c}	0.00± 0.00^{e}	6.00± 6.00^{b}	0.00± 0.00^{d}
Coefficient of Variation (%)	16.94	10.65	6.89	11.52	11.91	14.50	6.93	11.87	43.57	14.15

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Table 4.5: Abundance (mean ± SE) of insects associated with white yam in 2016/2017 in selected locations in Nigeria

Insects	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Araecerus fasciculatus	70.89±	49.67±	55.00±	41.67±	70.22±	64.56±	77.67±	64.56±	61.11±	33.89±
	9.21^{a}	2.70^{a}	9.90^{a}	9.13^{a}	6.42^{a}	5.00^{a}	4.00^{a}	5.00^{a}	2.10^{a}	1.10^{a}
Dinoderus minutus	11.22±	12.78±	6.00±	9.22±	0.00±	17.44±	6.67±	10.89±	19.78±	21.33±
	1.92^{b}	1.52^{cd}	0.74^{cd}	0.83^{b}	0.00^{d}	4.41^{bc}	1.42^{d}	2.31^{c}	2.30^{b}	1.62^{ab}
Rhyzopertha Dominica	26.44±	21.00±	27.56±	29.22±	39.00±	18.67±	21.00±	19.22±	0.00±	12.33±
	8.72^{b}	3.12^{b}	4.11^{ab}	1.84^{a}	1.92^{b}	0.73^{b}	0.22^{b}	1.32^{b}	0.00^{d}	6.62^{b}
Prostephanus truncatus	10.78±	22.22±	0.00±	0.00±	6.22±	0.00±	0.00±	0.00±	0.00±	0.00±
	2.90^{b}	1.10^{b}	0.00^{d}	0.00^{c}	1.62^{c}	0.00^{e}	0.00^{e}	0.00^{e}	0.00^{d}	0.00^{c}
Callosobruchus maculaus	0.00±	17.44±	0.00±	9.78±	0.00±	4.33±	0.00±	5.00±	0.00±	9.44±
	0.00^{c}	0.72^{bc}	0.00^{d}	0.43^{b}	0.00^{d}	0.23^{d}	0.00^{e}	0.22^{d}	0.00^{d}	0.10^{b}
Lasioderma serricorne	0.00±	11.89±	0.00±	4.44±	0.00±	4.7±	0.00±	15.00±	0.00±	11.00±
	0.00^{c}	0.82^{cd}	0.00^{d}	0.33^{b}	0.00^{d}	0.42^{d}	0.00^{e}	0.83^{bc}	0.00^{d}	1.22^{b}
Theocolax elegans	13.00±	8.33±	7.33±	11.00±	11.67±	10.00±	0.00±	11.33±	9.00±	0.00±
	1.53^{b}	0.92^{d}	0.72^{cd}	0.61^{b}	0.91^{c}	0.60^{cd}	0.00^{e}	1.22^{c}	1.51^{c}	0.00^{c}
Cephalonomia waterstoni	10.67±	0.00±	11.33±	0.00±	0.00±	11.67±	12.33±	11.33±	0.00±	10.67±
	1.82b	0.00^{e}	3.73^{bc}	0.00^{c}	0.00^{d}	0.92^{bc}	1.81^{c}	0.74^{c}	0.00^{d}	0.67^{b}
Coefficient of Variation (%)	17.96	7.77	23.59	15.35	10.29	10.79	8.59	8.70	8.97	24.95

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

(10.78 ± 2.90) and *L. serricorne* (4.44 ± 0.33) (Table 4.5). Moreover, the most abundant insect species on plantain were *S. zeamais* and *T. castaneum* and they were significantly higher than the population of other insect recorded (Table 4.6) across the selected locations.

The family/order wise percentage composition of insects associated with dried chips in selected locations shows Coleoptera and Hymenoptera were predominant orders. The order Coleoptera constituted between 78.2 to 100% on cassava and P ranging between 0 to 21.8% (Table 4.7). Of the coleopteran species, families Curculionidae (42.60%), Tenebrionidae (38.20), Bostrichidae (36.60%) and Anthribidae (33.80%) had higher percentage compositions than the family Chrysomelidae (16.40%) (Table 4.7). Moreover, the family/order wise percentage composition of insects associated with potato was only Coleoptera (Table 4.8). Family Bostrichidae had the highest percentage composition from between 0 to 100% than Curculionidae (30.4 - 41.2%) and Anobiidae (23.1-76.2%) while Anthribidae (0 - 36.70%) had the lowest percentage composition (Table 4.8). White yam also had higher family/order wise percent composition of Coleoptera than Hymenoptera. The order Coleoptera constitute between 79.4-100% while hymenoptera has 0-20.6%. Family Anthribidae had the highest percent composition than Bostrichidae and Chrysomelidae while family Bethylidae (0.00-12.60%) had higher percentage composition than Pteromalidae (0-10.60) (Table 4.9).

Similarly Order Coleoptera constituted the larger proportion of insects (82.6-94.3%) on white yam than insects associated with hymenoptera (9.2-17.4%). Family Anthribidae (34.4 - 67.9%) had the highest percent composition than the other families, (Table 4.10) while the family Anobiidae had the least percentage composition (0 - 11%). Plantain chips were infested by Curculionidae and Tenebrionidae had highest percentage composition than family Anthribidae and Bostrichidae. Coleopterans were found to be the dominant insect species complex on all the dried chips across the locations (Table 4.11).

4.3 Diversity of insect's species associated with selected dried chips

Table 4.12 to 4.16 give the diversity indices for the storage insects on dried chips of cassava, potato, water yam, white yam and plantain in the selected locations. The species

Table 4.6: Abundance (mean ± SE) of insects associated with plantain in 2016/2017 in selected locations in Nigeria

Insects	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Sitophilus zeamais	19.11± 2.22[a]	0.00± 0.00[c]	27.11± 1.82[a]	19.22± 1.32[a]	23.89± 2.33[a]	16.00± 3.00[a]	28.33± 1.52[a]	18.22± 1.42[a]	31.67± 6.11[a]	17.11± 0.44[a]
Tribolium castaneum	23.33± 1.82[a]	17.67± 0.92[a]	21.20± 2.00[a]	6.22± 1.62[b]	20.67± 0.83[a]	14.78± 1.51[ab]	23.67± 1.00[b]	13.22± 0.92[b]	14.11± 4.54[b]	0.00± 0.00[b]
Araecerus fasciculatus	9.44± 2.32[b]	9.67± 1.53[b]	0.00± 0.00[b]	9.06± 1.73[b]	0.00± 0.00[b]	10.11± 0.82[ab]	0.00± 0.00[c]	0.00± 0.00[c]	0.00± 0. 00[c]	0.00± 0.00[b]
Dinoderus minutus	14.56± 0.33[ab]	23.11± 0.52[a]	0.00± 0.00[b]	5.44± 1.13[b]	0.00± 0.00[b]	8.56± 0.92[b]	0.00± 0.00[c]	0.00± 0.00[c]	0.00± 0.00[c]	0.00± 0.00[b]
Coefficient of Variation (%)	10.02	7.42	8.42	12.80	7.80	10.90	5.24	7.42	26.11	2.63

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Table 4.7: Order/Family-wise percent composition of insects associated with cassava in 2016 and 2017 in selected locations in Nigeria

Order/Family	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Curculionidae	28.90	11.50	35.70	29.90	6.20	0.00	14.10	12.10	42.60	26.70
Tenebrionidae	35.80	16.10	31.80	22.30	38.20	23.20	28.80	22.60	13.00	18.10
Anthribidae	3.40	27.20	0.00	14.60	33.80	16.80	25.10	11.10	14.05	2.70
Bostrichidae	21.80	32.60	21.10	22.40	0.00	36.60	17.80	35.50	19.00	29.80
Chrysomelidae	0.00	9.40	0.00	12.10	0.00	16.40	0.00	7.00	0.00	16.20
Total (Coleoptera)	89.80	96.70	88.60	94.40	78.20	100.00	83.80	88.30	89.10	93.50
Pteromalidae	10.20	3.30	11.40	5.60	21.80	0.00	16.20	11.70	10.90	6.50

Table 4.8: Order/Family-wise percent composition of insects associated with potato in 2016 and 2017 in selected locations in Nigeria

Order/Family	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Curculionidae	39.60	41.20	0.00	30.40	0.00	0.00	0.00	0.00	0.00	0.00
Anthribidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.70	0.00	0.00
Bostrichidae	60.40	37.40	100.00	0.00	100.00	50.50	100.00	41.20	100.00	23.80
Anobiidae	0.00	21.40	0.00	69.60	0.00	49.50	0.00	23.10	0.00	76.20
Total (Coleoptera)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4.9: Order/Family-wise percent composition of insects associated with water yam in 2016 and 2017 in selected locations in Nigeria

Order/Family	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Anthribidae	52.90	29.90	69.30	52.20	63.10	51.00	89.40	50.00	89.50	48.40
Bostrichidae	26.80	38.40	10.10	40.60	22.00	37.10	0.00	31.70	0.00	23.00
Chrysomelidae	0.00	10.70	0.00	3.60	0.00	2.90	0.00	12.20	0.00	15.50
Anobiidae	0.00	10.80	0.00	3.60	0.00	3.00	0.00	0.00	0.00	13.10
Total (Coleoptera)	79.70	89.70	79.40	100.00	85.00	94.10	89.40	93.90	89.50	100.00
Pteromalidae	7.70	5.00	9.90	0.00	7.50	5.90	10.60	6.10	0.00	0.00
Bethylidae	12.60	5.30	10.70	0.00	7.50	0.00	0.00	0.00	10.50	0.00
Total (Hymenoptera)	20.30	10.30	20.60	0.00	15.00	5.90	10.60	6.10	10.50	0.00

Table 4.10: Order/Family-wise percent composition of insects associated with white yam in 2016 and 2017 in selected locations in Nigeria

Order/Family	Oyo		Osun		Ondo		Kwara		Ekiti	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Anthribidae	49.60	34.70	51.30	39.60	55.30	49.10	66.00	47.00	67.90	34.40
Bostrichidae	33.90	39.10	31.30	36.50	35.50	27.40	23.50	21.90	22.10	34.10
Chrysomelidae	0.00	12.20	0.00	9.30	0.00	3.40	0.00	3.60	0.00	9.60
Anobiidae	0.00	8.30	0.00	4.20	0.00	3.60	0.00	10.90	0.00	11.00
Total(Coleoptera)	83.50	94.30	82.60	89.60	90.80	83.50	89.50	83.40	90.00	89.20
Pteromalidae	9.10	5.80	6.80	10.40	9.20	7.60	0.00	8.30	10.00	0.00
Bethylidae	7.40	0.00	10.60	0.00	0.00	8.90	10.50	8.30	0.00	10.80
Total (Hymenoptera)	16.50	5.80	17.40	10.40	9.20	16.50	10.50	16.60	10.00	10.80

Table 4.11: Order/Family-wise percent composition of insects associated with plantain in 2016 and 2017 in selected locations in Nigeria.

Order/Family	**Oyo**		**Osun**		**Ondo**		**Kwara**		**Ekiti**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Curculionidae	28.70	0.00	56.10	48.00	53.60	32.40	54.50	58.00	69.20	100.00
Tenebrionidae	35.10	35.00	43.90	15.50	46.40	29.90	45.50	42.00	30.80	0.00
Anthribidae	14.20	19.20	0.00	23.00	0.00	20.50	0.00	0.00	0.00	0.00
Bostrichidae	21.90	45.80	0.00	13.50	0.00	17.20	0.00	0.00	0.00	0.00
Total (Coleoptera)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

richness varied based on the food host ranging from 1-8, with potato having the lowest richness ranging from 1-3 species. On plantain the richness ranged from 1-4 species while other dried chips contained higher insect richness ranging from 2-8 species. The species richness and other diversity indices on insects associated with cassava varied across the locations in two years (Table 4.12). The species richness of insects ranged from 4-8, while the Simpson, Shannon, Evenness and Margalef diversity indices ranged from 0.69-0.86, 1.24-2.01,0.74-0.97 and 0.59-1.44 on cassava respectively. Moreover, insect species richness on Potato ranged from 1-3 while the Simpson, Shannon, Evenness and Margalef diversity indices ranged from 0-0.65,0-1.1,0.87-1.0, 0-0.55 respectively (Table 4.13).

Water yam had insect species richness ranging from 2-8, while Simpson, Shannon, Evenness and Margalef diversity indices ranged from 0.19-0.67,0.33-1.88,0.64-0.86,0.22-1.32 respectively (Table 4.14). Furthermore, the species richness of insect on white yam ranged from 3-7, while the Simpson, Shannon, Evenness and Margalef diversity indices ranged from 0.48-0.80, 0.83-1.78,0.67-0.88,0.45-1.23 respectively (Table 4.15). Plantain has insect species richness ranging from 1 - 4, while the Simpson, Shannon, Evenness and Margalef diversity indices ranged from 0 - 0.73, 0 - 1.35, 0.87 - 1.0, 0 - 0.81 respectively (Table 4.16). Sampling analysis showed a varied species richness of 8, 7, 4 and 3 in cassava and water yam; white yam; plantain and potato respectively centered on the rarefaction curve derived from the sampling study's gathered data. The value of species richness was established by Jacknife 1 and Chao indices and a similar result were obtained (Table 4.12 - 4.16). This depicts the most likely species expected to be recognized among these locations and on the dried chips, was realized. Insect community structure estimation in the selected food hosts as groups in all the selected food hosts (Figure 1- 5). The composition of each grouping varies, but the first group distinctly composed of coleopterans and the second group hymenoptera (Figure 1-5).

4.4. Pesticide residues analyses in dried cassava and water yam chips from selected locations

A total of four organochlorine (OC) residues: endosulfan I, methoxychlor, P,P^{1} DDT, and Endrin Aldehyde were detected (Table 4.17). The average amount (Mean Concentration)

Table 4.12: Diversity indices of insects associated with cassava in 2016/2017 in selected locations in Nigeria

	Oyo		**Osun**		**Ondo**		**Kwara**		**Ekiti**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Taxa	6.00	8.00	4.00	8.00	4.00	7.00	5.00	8.00	5.00	8.00
Individuals	147.78	277.00	160.88	154	119.33	146.67	150.22	127.99	115.89	161.12
Simpson(1-D)	0.74	0.84	0.71	0.84	0.69	0.84	0.79	0.86	0.73	0.83
Shannon(H)	1.50	1.95	1.31	1.94	1.24	1.89	1.58	2.01	1.47	1.91
Evenness (e^H/S)	0.75	0.88	0.93	0.87	0.86	0.94	0.98	0.94	0.87	0.84
Margalef	1.00	1.25	0.59	1.39	0.63	1.20	0.80	1.44	0.84	1.38

Table 4.13: Diversity indices of insects associated with potato in 2016/2017 in selected locations in Nigeria

	Oyo		**Osun**		**Ondo**		**Kwara**		**Ekiti**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Taxa	2.00	3.00	1.00	2.00	1.00	2.00	1.00	2.00	2.00	2.00
Individuals	34.78	37.22	31.67	34.78	32.33	33.67	25.11	24.78	20.22	37.33
Simpson(1-D)	0.48	0.65	0.00	0.42	0.00	0.50	0.00	0.46	0.43	0.36
Shannon(H)	0.67	1.06	0.00	0.61	0.00	0.69	0.00	0.65	0.63	0.55
Eveness (e^H/S)	0.98	0.97	1.00	0.92	1.00	1.00	1.00	0.96	0.94	0.87
Margalef	0. 28	0.55	0.00	0.28	0.00	0.28	0.00	0.31	0.33	0.28

Table 4.14: Diversity indices of insects associated with water yam in 2016/2017 in selected locations in Nigeria

	Oyo		**Osun**		**Ondo**		**Kwara**		**Ekiti**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Taxa	5.00	8.00	4.00	6.00	4.00	6.00	2.00	5.00	2.00	4.00
Individuals	116.90	200.34	134.44	160.12	138.72	145.88	94.33	148.44	57.00	119.11
Simpson(1-D)	0.66	0.81	0.49	0.66	0.54	0.66	0.19	0.67	0.19	0.67
Shannon(H)	1.33	1.88	0.953	1.35	1.01	1.34	0.34	1.30	0.34	1.24
Evenness (e^H/S)	0.76	0.82	0.65	0.64	0.69	0.64	0.70	0.74	0.70	0.87
Margalef	0.84	1.32	0.61	0.99	0.61	1.00	0.22	0.80	0.25	0.63

Table 4. 15: Diversity indices of insects associated with white yam in 2016/2017 in selected locations in Nigeria

	Oyo		**Osun**		**Ondo**		**Kwara**		**Ekiti**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Taxa	6.00	7.00	5.00	6.00	4.00	7.00	4.00	7.00	3.00	6.00
Individuals	143.00	143.33	107.22	105.33	127.11	131.45	117.67	137.33	89.89	98.66
Simpson(1-D)	0.69	0.80	0.65	0.74	0.59	0.71	0.52	0.73	0.48	0.79
Shannon(H)	1.47	1.78	1.27	1.53	1.06	1.54	0.98	1.61	0.83	1.67
Evenness (e^H/S)	0.72	0.85	0.72	0.77	0.72	0.67	0.67	0.71	0.76	0.88
Margalef	1.01	1.21	0.86	1.07	0.62	1.23	0.63	1.22	0.45	1.09

Table 4.16: Diversity Indices of Insects Associated with Plantain in 2016/2017 in Selected locations in Nigeria

	Oyo		**Osun**		**Ondo**		**Kwara**		**Ekiti**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Taxa	4.00	3.00	2.00	4.00	2.00	4.00	2.00	2.00	2.00	1.00
Individuals	66.44	50.45	48.33	39.94	44.56	49.45	52.00	31.44	45.78	17.11
Simpson(1-D)	0.73	0.63	0.49	0.67	0.50	0.73	0.50	0.49	0.43	0.00
Shannon(H)	1.34	1.04	0.69	1.25	0.69	1.35	0.69	0.68	0.62	0.00
Evenness (e^H/S)	0.95	0.94	0.99	0.87	0.99	0.97	0.99	0.99	0.93	1.00
Margalef	0.72	0.51	0.26	0.81	0.26	0.77	0.25	0.29	0.26	0.00

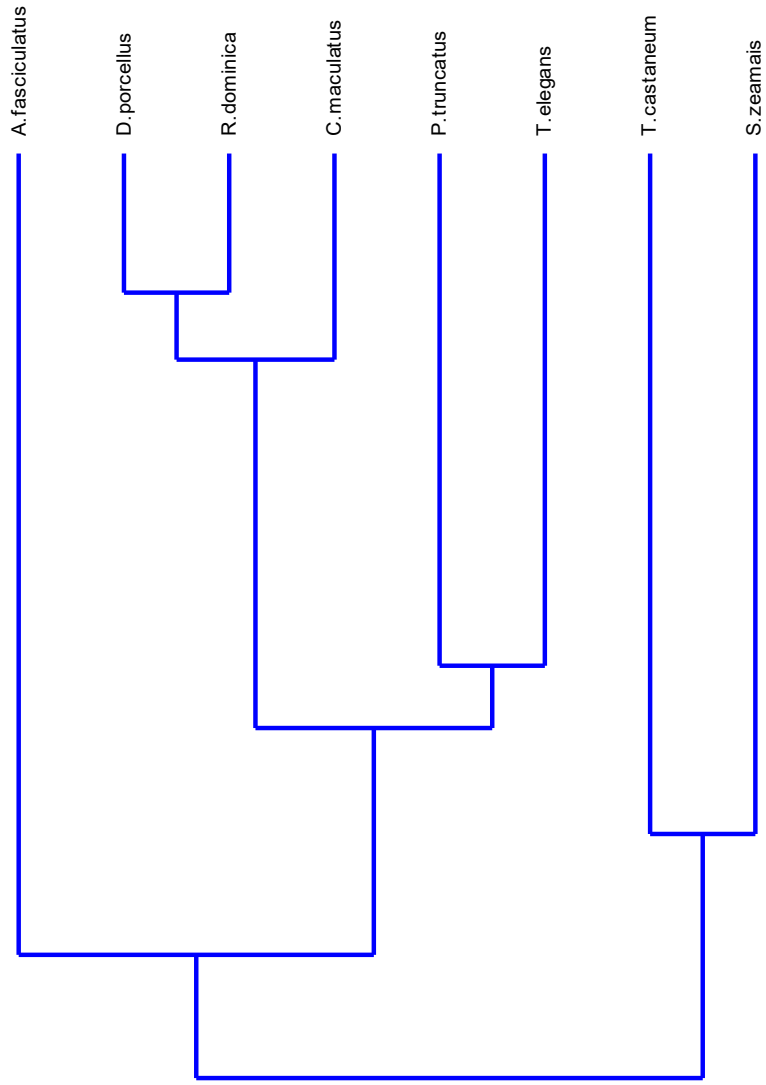


Figure 4.1: Hierarchical classification of insect pests on Casssava dried chips

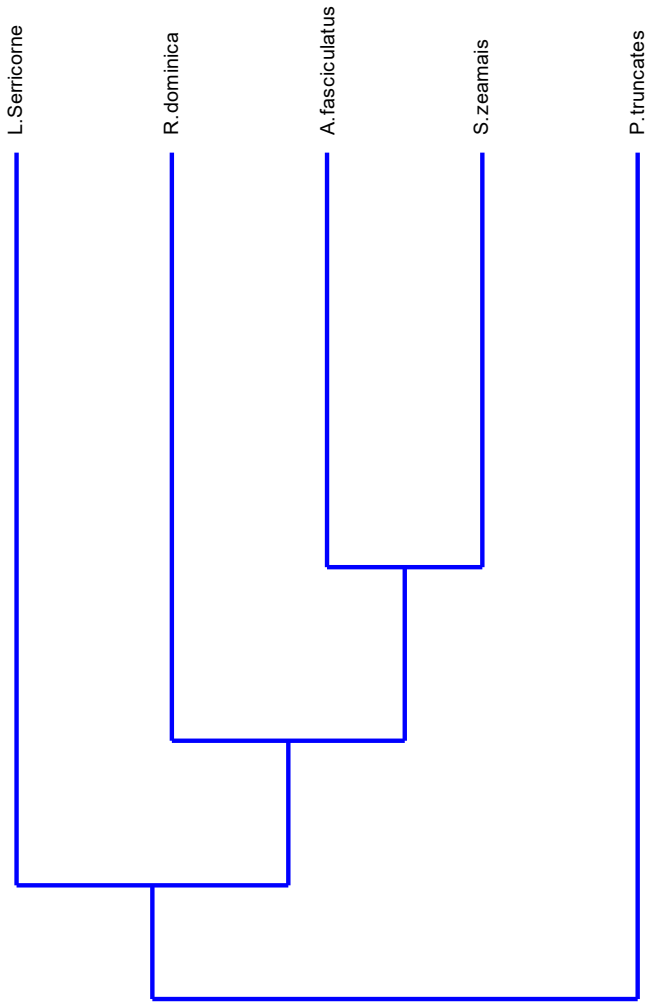


Figure 4.2: Hierarchical classification of insect pests on Potato dried chips

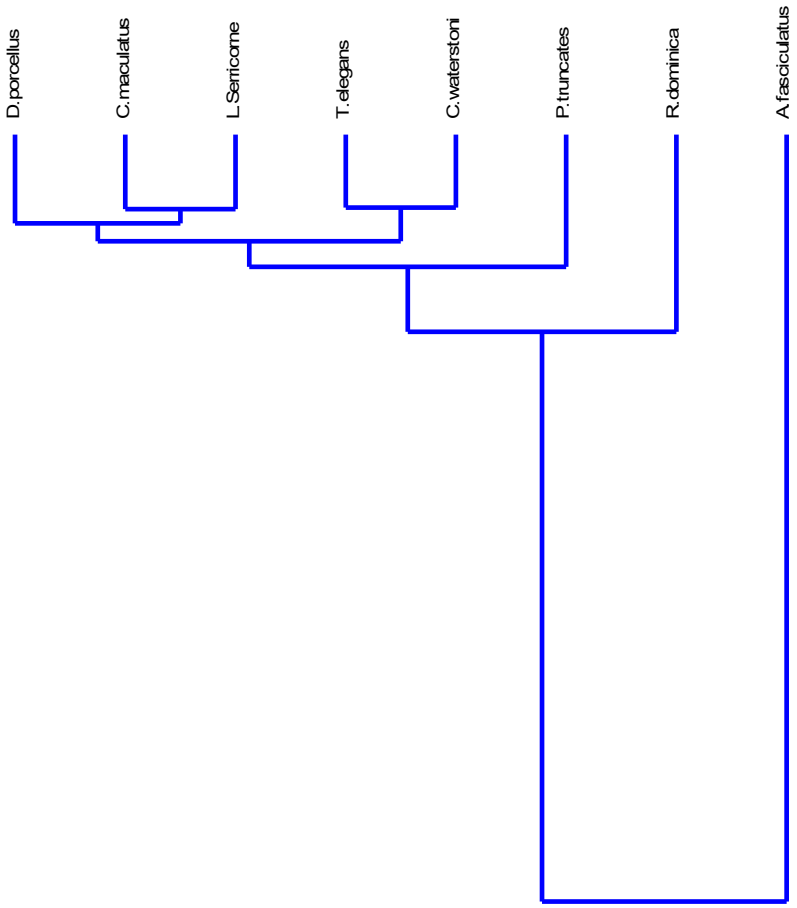


Figure 4.3: Hierarchical classification of insect pests on Water yam dried chips

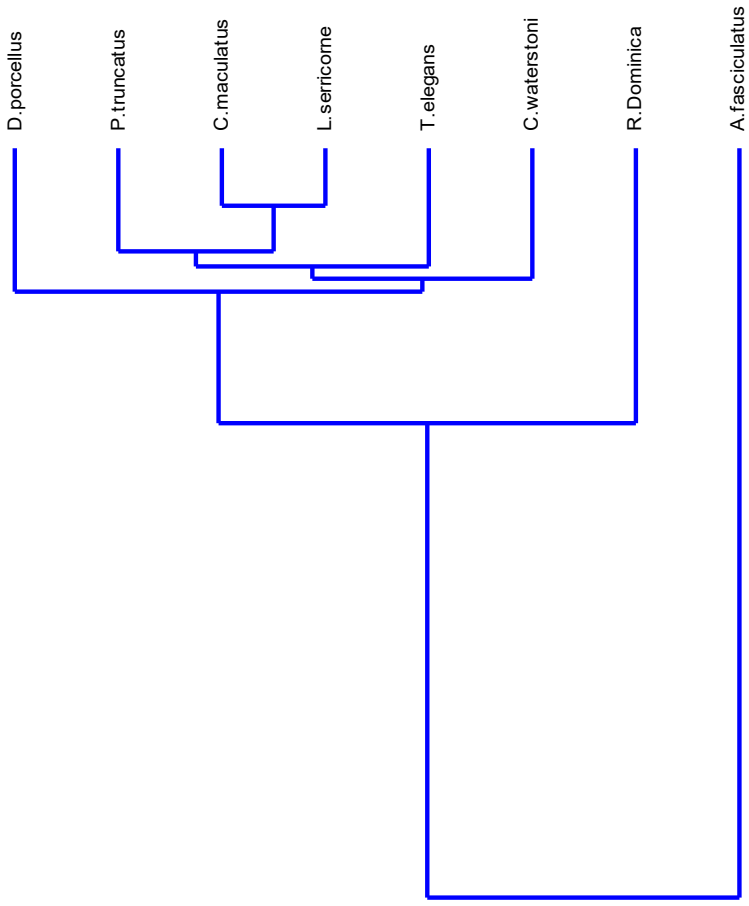


Figure 4.4: Hierarchical classification of insect pests on Water yam dried chips

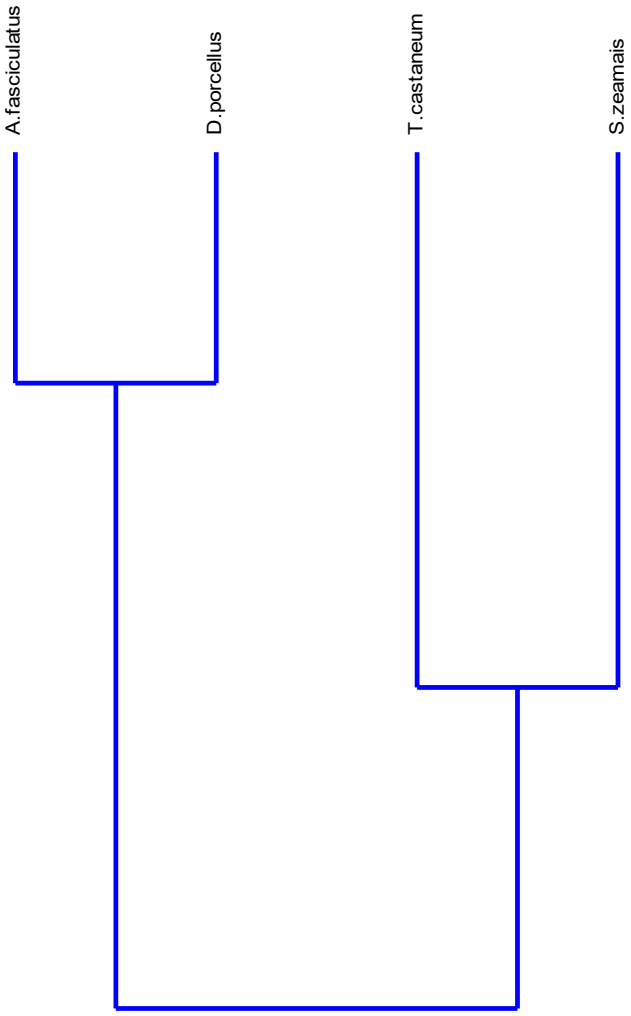


Figure 4.5: Hierarchical classification of insect pests on Plantain dried chips

Table 4.17: Mean Concentration (mg kg^{-1}) ± SE of organochlorine residues in dried cassava and yam chips from selected locations

	Cassava			White yam		
Pesticides	Ibadan	Osogbo	Ilorin	Ibadan	Osogbo	Saki
P,P[1] DDT	ND	ND	0.118±0.059	0.125 ± 0.031	0.115±0.065	0.096±0.029
			(0.012-0.215)	(0.090-0.187)	(0.040-0.244)	(0.045-0.145)
Endrin Aldehyde	ND	ND	0.129±0.004	0.143±0.035	0.073±0.037	0.092±0.030
			(0.091-0.197)	(0.074-0.186)	(0.034-0.147)	(0.037-0.139)
Endosulfan	0.071±0.039	ND	0.078± 0.035	0.071±0.034	0.066±0.069	0.070±0.030
	(0.027-0.148)		(0.029-0.059)	(0.036-1.139)	(0.026-0.135)	(0.026-0.127)
Methoxychlor	0.060±0.038	ND	0.146 ± 0.069	0.074± 0.033	0.159±0.035	0.064±0.015
	(0.017-0.136)		(0.074-0.284)	(0.034-0.140)	(0.089-0.297)	(0.048-0.095)

n = 3 for each market

ND = Not detected

SE = Standard error of mean

of organochlorine residues present in dried cassava and yam chips from selected locations is presented in Table 4.17. The average amount of residues in the dried cassava samples from Ibadan market ranged from not detected (ND) (P,P^1 DDT, and Endrin Aldehyde) to 0.071 mgkg^{-1} ± 0.039 (Endosulfan I), pesticides residues were totally absent from cassava in Osogbo markets while samples from Ilorin market ranged from 0.078 mgkg^{+1} ± 0.035 (Endosulfan) to 0.146 mgkg^{-1} ± 0.069 (Methoxychlor) (Table 4.17). Nonetheless, in dried yam chips, The mean residue levels identified in Ibadan market samples varied from 0.071 mgkg-1 to 0.034 mgkg-1 (Endosulfan) to 0.143 mgkg^{-1} ± 0.035 (Endrin Aldehyde) while in Osogbo market, the mean concentration ranged from 0.066 mgkg^{-1} ± 0.069 (Endosulfan) to 0.159 mgkg^{-1} ± 0.035 (Methoxychlor), while residues detected in samples from Saki ranged from 0.064 mgkg^{-1} ± 0.015 (Methoxychlor) to 0.096 mgkg^{-1} ± 0.029 (P,P^1 DDT) (Table 4.17)

The mean residue levels identified in cassava and dried yam chips from selected locations. Only four OC pesticide residues were identifed in most of the samples out of seventeen that was tested. The most predominant residue in all the samples was Endosulfan followed by Methoxychlor. In cassava from Ibadan markets Endosulfan accounted for 54% at a mean concentration of 0.071±0.039 mgkg^{-1}, 36% of Methoxychlor was present at a mean concentration of 0.060 ± 0.038 mgkg^{-1}, while P,P^1 DDT and Endrin Aldehyde were totally absent (Tables 4.17 & 4.18). The most predominant residue in white yam samples from Ibadan was Endrin Aldehyde which accounted for 35% at an average amount of 0.143±0.035 mgkg^{-1} .This was followed by P,P^1 DDT with an average concentration of 0.125 ± 0.031 mgkg^{-1} (30%), Methoxychlor accounted for 18% with an average concentration of 0.074± 0.033 mgkg^{-1}, while Endosulfan accounted for 17% at a mean concentration 0.071±0.034 (Tables 4.17 - 4.19). White yam samples obtained from Osogbo was predominant in Methoxychlor with a mean residue of 0.159±0.035 mgkg^{-1}(39%) followed by P,P^1 DDT with an average residue of 0.115±0.065 mgkg^{-1} (28%), 18% of Endrin Aldehyde at a mean concentration of 0.073±0.037 mgkg^{-1} while the least is the 16% Endosulfan with an average residue of 0.066±0.069 mgkg^{-1} (Tables 4.17 – 4.19). White yam obtained from Saki was predominant with residue of P,P^1 DDT with a mean residue of 0.096±0.029 mgkg^{-1} (30%). This was followed by Endrin Aldehyde with a average concentration of 0.092±0.030 mgkg^{-1} (28%) while Endosulfan and Methoxychlor

Table 4.18: Mean concentration (mg kg-^{1}) ± SE and percentage of organochlorine residues detected in dried cassava and yam chips from selected locations

	Cassava				**White yam**					
Pesticides	**Ibadan**		**Ilorin**		**Ibadan**		**Osogbo**		**Saki**	
	Mean ± SE (mg kg^{-1})	**%**	**Mean ± SE (mg kg^{-1})**	**%**	**Mean ± SE (mg kg^{-1})**	**%**	**Mean ± SE (mg kg^{-1})**	**%**	**Mean ± SE (mg kg^{-1})**	**%**
P,P^{1} DDT	ND	0	0.118±0.059	25	0.125 ± 0.031	30	0.115±0.065	28	0.096±0.029	30
Endrin Aldehyde	ND	0	0.129±0.004	27	0.143±0.035	35	0.073±0.037	18	0.092±0.030	28
Endosulfan	0.071±0.039	54	0.078±0.035	17	0.071±0.034	17	0.066±0.069	16	0.070±0.030	22
Methoxychlor	0.060±0.038	46	0.146±0.069	31	0.074± 0.033	18	0.159±0.035	39	0.064±0.015	20

Table 4.19: Highest pesticide residues on dried cassava and yam chips from selected locations compared with EU's maximum residue limits ($mgkg^{-1}$)

	Highest amount found		EU's Maximum Residue Limit			
Pesticides	Cassava	White Yam	Cassava (2010)	Cassava (2019)	White Yam (2010)	White Yam (2019)
P,P[1] DDT	0.215	0.244	0.02	0	0.02	0
Endrin Aldehyde	0.197	0.186	0.01	0	0.01	0
Endosulfan	0.148	1.139	0.05	0	0.05	0
Methoxychlor	0.284	0.297	0.01	0	0.01	0

was also recorded with a average concentration of 0.070±0.030 $mgkg^{-1}$ (22%) and 0.064±0.015 $mgkg^{-1}$ (20%), respectively (Tables 4.17 - 4.19).

4.5. Life history and description of the life stages of *Araecerus. fasciculatus* on selected dried chips

Araecerus fasciculatus comprises of seven different life stages: egg, four larval instars, prepupa/pupa and adult. There was variation in the study conducted on description and developmental biology of *A fasciculatus* reared on different dried chips displayed onset of oviposition at 6 to 7 days after emergence and it lasted till the 23rd day. There exists difference significantly in oviposition period recorded on different dried chips, coffee bean weevil had a longer oviposition period on cassava, white yam and water yam (16.5±0.63, 15.25±0.25 and 15.5±0.29 days) than on plantain and potato (14.75±0.65 and 12.5±0.65 days) (Table 4.20)

Copulation started 4 to 6 days after emergence, male are observed mounting the female and their genitals abdominal tip touches each other and is glued together. On all dried chips it was observed that male matured in 3 days while female matured in 6 days. Eggs were laid immediately after mating. Mating occurred at both night and day. Mating period ranged from 2 to 12 minutes. Coffee bean weevil reared on white yam had a longer period of copulation (8.50±0.25 minutes). The lowest copulation period was recorded on potato chips (6.00±0.75 minutes), which was different significantly from those recorded on water yam, cassava and plantain chips (6.75±0.5, 6.75±0.25 and 7.25±0.58 minutes) respectively, (Table 4.20).

Each female laid 3-5 egg per day. They usually used their beak to drill hole on dried chips to deposit the eggs. They laid eggs on the both inside and outside of the food substrate. One egg per hole was observed. Time range to lay egg was 7-10 minutes. Egg colour was white and they turned yellowish when mixed with acid fuschin solution. They are ovoid to spherical in shape. The colour of the eggs after some hours changed to cream and hatched into apodous larva with a sclerotized brownish head that is cream whitish in colour, incubation period of the egg range between 3 to 7 days, there exists no different in egg incubation period on all dried chips. Total average amount of eggs laid varied

Table 4.20 Developmental parameters (mean ± SE) of *A. fasciculatus* on selected dried chips

	Mating Period (Minutes)	**Oviposition period (Days)**	**Egg Incubation (ns) (Days)**	**Fecundity**	**Adult longevity (Days)**	**Developmental periods (Days)**
Cassava	6.75 ±0.25^{ab} (2-11)	15.25±0.25^{a} (6-23)	3.50±0.29 (3-6)	61.50±4.05^{b} (53-72)	88.50±5.33^{b} (80-110)	47.00±0.91^{ab} (40-55)
Potato	6.00±0.75^{b} (2-10)	12.50±0.65^{b} (6-20)	3.75±0.48 (3-7)	52.5±7.46^{b} (48-65)	91.50±3.87^{ab} (80-102)	45.50±2.06^{ab} (37-55)
Water Yam	6.75±0.50^{ab} (2-11)	15.50±0.29^{a} (6-23)	3.75±0.48 (3-6)	93.50±4.42^{a} (80-111)	1050±0.96^{a} (94- 112)	52.75±2.87^{a} (35-60)
White Yam	8.50±0.25^{a} (2-12)	16.50±0.63^{a} (6-23)	4.75±0.48 (3-6)	100.00±3.24^{a} (70-112)	99.50±1.94^{ab} (98-103)	49.75±1.93^{ab} (33-57)
Plantain	7.25±0.58^{ab} (2-11)	14.75±0.65^{ab} (6-22)	3.75±0.48 (3-7)	58.00±4.41^{b} (50-71)	66.50±4.17^{c} (62-89)	42.25±1.44^{b} (36-52)
Coefficient of Variation (%)	14.30	7.04	10.93	13.48	8.03	8.24

Tukey's HSD Test at α = 0.05 finds no significant differences between means within a column with the same letter(s).

*Range in Parenthesis (ns = no significant difference)

considerably. Among the dried chips, the highest mean fecundity was on white yam and water yam (100±3.24 and 93.5±4.42) while mean fecundity on potato ((52.5±7.46), cassava (61.5±4.05) and plantain (58±4.41) had the ratio varied from 1.28 to 1.67 across the larval instars' stages, having mean growth ratio of 1.5 (Table 4.23). It demonstrates that the head capsule measurement adheres to Dyar's rule, same level of significance (Table 4.23). Adult longevity of *A. fasciculatus* on different dried chips varied significantly (Table 4.20), adult coffee bean weevil significantly lived longer on water yam (105.0±0.9, 99 days), white yam (99.5±1.94 days) potato (91.5±3.87 days) than on plantain (88.5±5.33 days) and cassava (66.5±4.17 days) (Table 4.20).

The developmental period of the life stages of larva instars varied significantly ($P < 0.05$) on all the dried chips used (Table 4.21). Basically, coffee bean weevil larva instar first stage had an approximately mean developmental period of 3.75 to 5.5 days irrespectives of the dried chips used. The larval instar second stage took 4.75 to 5.75 (4-6 days). The mean developmental period on larval instar third stage range from 4.75 to 5.75 (4-6 days). Larval instar fourth stage has mean ranged from 5.5 to 6.75 (5 - 7days) which changed into white and slender head pre pupa and later changed into pupa few hours, pupa stage range between 2 to 4 days. (Table 4.21). Egg to adult Developmental period significantly varied among dried chips. It was significantly higher in water yam (52.75±2.87days) than cassava (47±0.91 days), white yam (45.5±2.06 days) and potato (49.75±1.93 days) respectively and plantain (42.25±1.44 days) had the lowest developmental period.

Dried chips significantly ($P < 0.05$) influenced body morphology of adult *A. fasciculatus* (Table 4.22). The morphology of immature stages of *A. fasciculatus* instar larvae between the dried chips were not the same significantly ($P < 0.05$) from one another among the dried chips used (Table 4.22). The adult male *A. fasciculatus* instar was significantly bigger on cassava (3.89±0.02 mm long and 1.28 ± 0.03 mm wide) and white yam (3.89±0.05mm long and 1.28 ± 0.03mm wide) and shortest on water yam (2.74 ± 0.04mm long and 1.06± 0.04 mm wide) but not significantly longer than the measurement on the body length and width of male *A. fasciculatus* on potato (2.88 ± 0.09 and 1.07 ± 0.01) and plantain (2.85 ± 0.03 and 1.07 ± 0.01). In addition to that, regardless of the food hosts, female *A. fasciculatus* were markedly bigger than males.

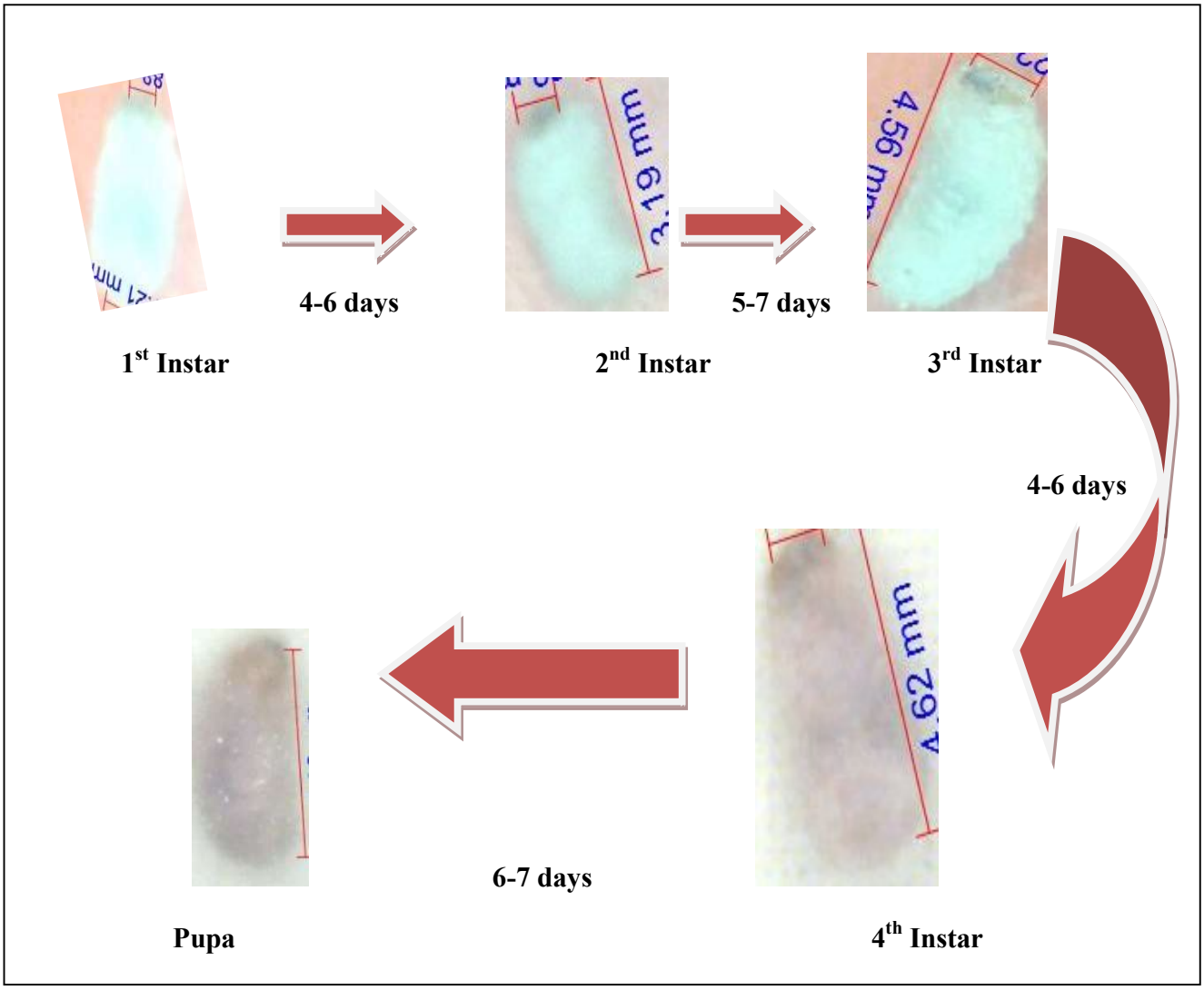


Plate 4.1: *Araecerus fasciculatus* larvae instars Developmental period on some stored food crops

Table 4.21. Developmental Periods (days) (mean ± SE) of the larva stages of *A. fasciculatus* selected dried chips

	1st Instar (ns)	2nd Instar (ns)	3rd Instar (ns)	4th Instar (ns)	Pre Pupa/Pupa (ns)
Cassava	3.75±0.25 (4-5)	5.00±0.41 (5-7)	5.00±0.41 (4-6)	6.50±0.29 (6-7)	3.00±0.41 (2-4)
Potato	5.00±0.29 (4-6)	5.50±0.25 (5-6)	5.50±0.25 (5-6)	6.0±0.25 (5-7)	3.75±0.29 (3-4)
Water Yam	5.50±0.29 (5-6)	5.75±0.29 (6-7)	5.75±0.29 (5-6)	6.25±0.25 (6-7)	3.50±0.29 (3-4)
White Yam	5.50±0.25 (5-6)	4.75±0.41 (6-7)	4.75±0.41 (4-6)	6.75±0.29 (6-7)	3.50±0.48 (3-4)
Plantain	4.25±0.41 (4-5)	5.25±0.29 (5-7)	5.25±0.29 (4-6)	5.50±0.41 (5-6)	3.25±0.25 (2-4)

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Table 4.22: Morphology (mm) ± S.E of the life stages of *A. fasciculatus* on selected dried chips

	1st Instar		2nd Instar		3rd Instar		4th Instar		PrePupa/Pupa		Adult Male		Adult Female	
Dried Chips	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**	**Length (mm)**	**Width (mm)**
Cassava	3.18± 0.01^{a}	0.78± 0.01^{a}	3.89± 0.02^{a}	0.94± 0.03^{b}	4.56± 0.24	1.43± 0.01^{c}	5.80± 0.03	1.90± 0.01	3.83± 0.03	1.85± 0.03	3.89± 0.02^{a}	1.28± 0.03^{a}	4.88± 0.01^{a}	1.12± 0.01^{c}
Potato	3.16± 0.01^{b}	0.76± 0.01^{ab}	3.66± 0.02^{b}	1.17± 0.02^{ab}	4.80± 0.10	1.37± 0.01^{d}	5.65± 0.01	1.76± 0.03	3.88± 0.06	1.86± 0.03	2.88± 0.09^{b}	1.07± 0.01^{b}	3.79± 0.02^{b}	1.63± 0.01^{a}
Water Yam	3.16± 0.01^{b}	0.73± 0.01^{bc}	3.69± 0.02^{b}	1.3± 0.11^{a}	4.65± 0.09	1.51± 0.01^{b}	5.80± 0.03	1.94± 0.01	3.87± 0.02	1.94± 0.03	2.74± 0.04^{b}	1.06± 0.04^{b}	3.75± 0.02^{b}	1.08± 0.05^{c}
White Yam	3.19± 0.01^{a}	0.72± 0.01^{d}	3.90± 0.02^{a}	1.18± 0.09^{ab}	4.67± 0.10	1.76± 0.02^{a}	5.81± 0.05	1.93± 0.01	3.82± 0.05	1.76± 0.04	3.89± 0.05^{a}	1.28± 0.03^{a}	4.85± 0.15^{a}	1.43± 0.04^{b}
Plantain	3.18± 0.01^{a}	0.68± 0.01^{c}	3.86± 0.03^{a}	1.1± 0.10^{ab}	4.66± 0.03	1.46 0.01^{c}	6.01± 0.02	1.87± 0.01	3.86± 0.05	1.79± 0.01	2.85± 0.03^{b}	1.07± 0.01^{b}	4.59± 0.04^{a}	1.3± 0.05^{b}
C.V(%)	0.25	2.22	1.31	0.51	5.71	1.51	1.11	1.74	2.38	3.03	2.93	4.38	3.32	5.4

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

The width measurement of the head capsule of larval instars on a daily bases showed peaks of four frequency representing four larval instars (Table 4.23, Fig 4.6). Regardless of the food hosts, the head capsule width increased with each consecutive instar. The growth ratio (Dyar and a t-value higher than 3.182 was required to establish a significant difference between the observed average head capsule width and the estimated average (d) based on a t-test for differences between the observed and calculated averages. Nonetheless, a t-value less than 3.182 was estimated (Table 4. 23) suggesting that there was no difference significant and that the data followed Dyar's rule. The connection between the larval developmental period and the average head capsule width was consistent, and regular geometric larval growth was seen across the dried chips in each instar, the average width of thr head capsule was compared to the larval instar stage (Table 4. 23 and Fig 4.7). From all of the dried chips, linear regression analysis revealed a strong correlation between larval instars and head capsule width.

4.6. Food host preference of *Araecerus fasciculatus*

The mean number of *A. fasciculatus* found on different food hosts after 24-, 48- and 72-hours post – infestation/introduction in the choice chamber (Table 4.24). There was a significant difference in the average number of *A. fasciculatus* attracted to the food hosts at 24, 48 and 72 hours post introduction period. At 24 and 48 hours, *A. fasciculatus* significantly preferred cassava and plantain (11.67; 11.66 and 11.67; 10.33) than white yam, water yam and sweet potatoes, the least preferred host at 24 hours was sweet potato (6.67), although there exists no difference in the preference of white yam and water yam. At 48 hours the least preferred was sweet potato (7.00) and white yam (6.00) but there exists no difference significantly ($P < 0.05$) between the two. The preference of *A. fasciculatus* at 72 hours post – infestation was plantain (13.00), which was statistically higher ($P < 0.05$) than other host preference. This was followed by white yam (10.33) > cassava (8.00) > water yam (6.67) > sweet potato (5.33).

Table 4.23: Head Capsule width for larval instars of *A. fasciculatus* and test for conformity to Dyar's rule

	Cassava				Potato				Water yam				White yam				Plantain			
Instar	Observed Average (mm)	Growth Ratio	Calculated Average	Differences	Observed Average (mm)	Growth Ratio	Calculated Average	Differences	Observed Average (mm)	Growth Ratio	Calculated Average	Differences	Observed Average (mm)	Growth Ratio	Calculated Average	Differences	Observed Average (mm)	Growth Ratio	Calculated Average	Differences
I	0.27	-	-	-	0.27	-	-	-	0.27	-	-	-	0.27	-	-		0.27	-	-	-
II	0.44	1.63	0.39	0.05	0.43	1.59	0.40	0.02	0.44	1.62	0.39	0.05	0.43	1.62	0.39	0.04	0.45	1.67	0.39	0.06
111	0.64	1.46	0.64	0.00	0.62	1.44	0.62	0.02	0.65	1.48	0.64	0.01	0.64	1.49	0.63	0.01	0.65	1.44	0.66	-0.01
1V	0.82	1.28	0.93	-0.11	0.82	1.32	0.90	-0.07	0.83	1.28	0.95	-0.12	0.82	1.28	0.93	-0.11	0.83	1.28	0.95	-0.12
Mean growth Ratio		1.5				1.5				1.5				1.5				1.5		
Average Difference (d)				-0.02				-0.01				-0.02				-0.02				-0.02
Standard Deviation of Differences				0.08				0.05				0.09				0.07				0.09
T calculated				-0.75				-0.58				-0.05				-0.91				-0.77
T tabulated				3.182				3.182				3.182				3.182				3.182

Reject Ho if T calculated > T tabulated

Decision: Do not reject Ho, growth ratio conforms to Dyar's rule

Note: Growth ratio- the mean head capsule width of a succeeding instar divided by the mean head capsule width of a preceding instar

Calculated average – observed mean head width of a preceding instars multiplied by the mean growth ratio.

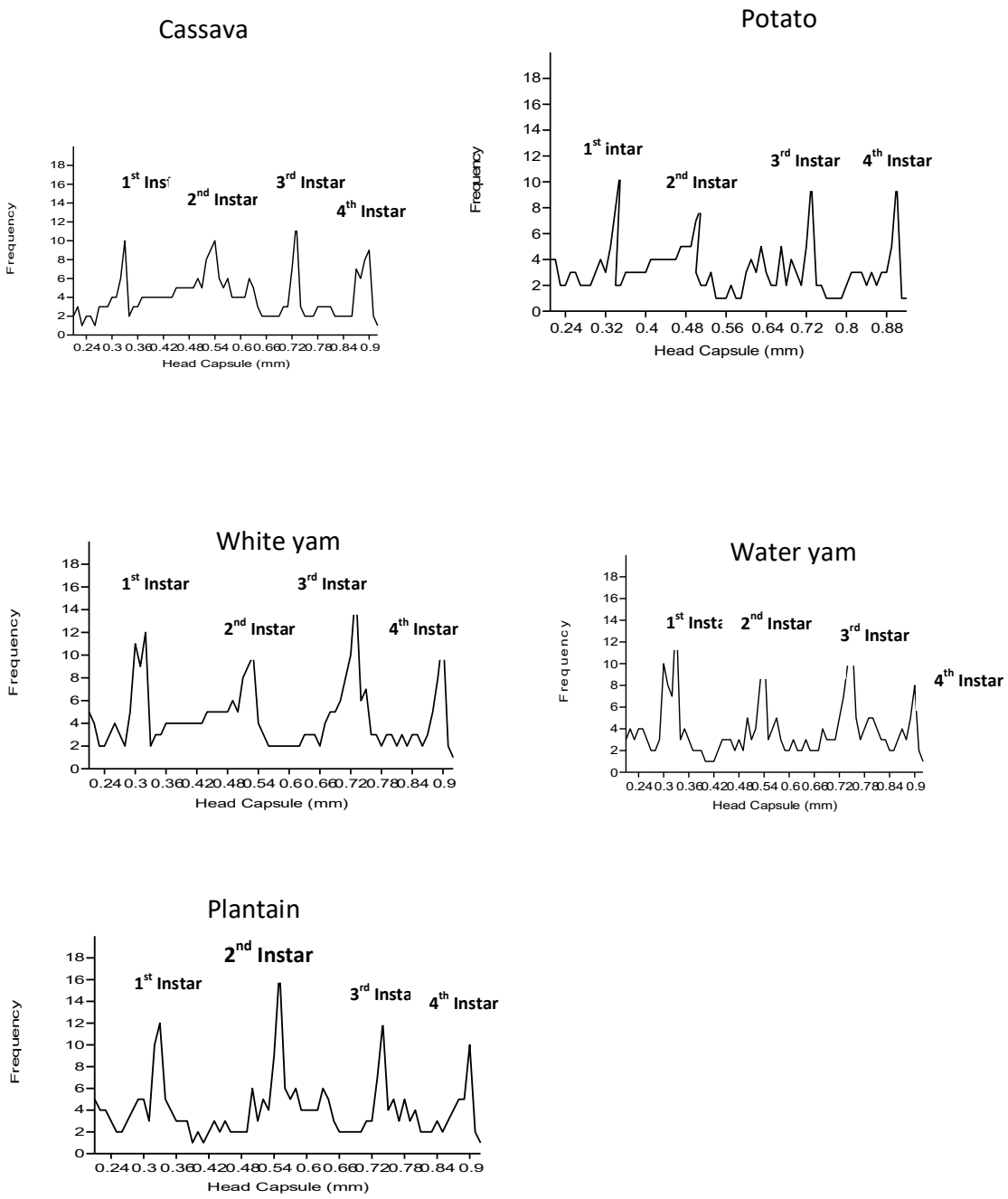


Fig. 4.6 : Frequency distribution of the head capsule width of larval instar of *A. fasciculatus* on selected dried chips

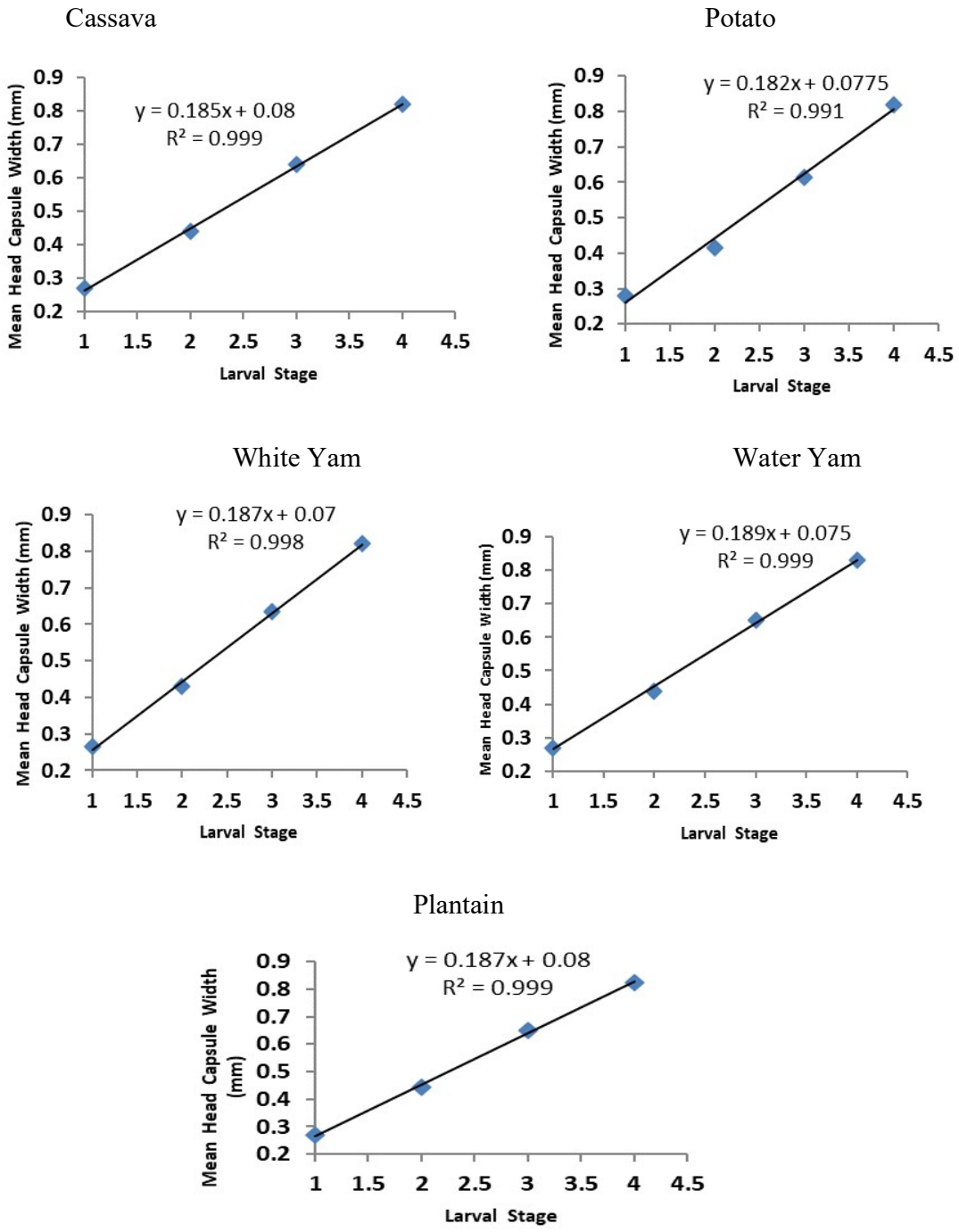


Figure 4.7: Relationship between head capsule width and larval development stage of *A. fasciculatus* on selected dried chips

Table 4.24 Mean number of *Araecerus fasciculatus* associated with dried chips in choice host preference study after 24, 48, and 72 hours of infestation

	Duration of Introduction		
	24 hours	48 hours	72 hours
Cassava	11.67±0.88^{a}	11.67±0.33^{a}	8.00±0.54^{bc}
Sweet potato	6.67±0.33^{b}	7.00±0.58^{c}	5.33±0.25^{c}
Water yam	7.33±0.33^{b}	8.67±0.33^{bc}	6.67±1.44^{c}
White yam	8.67±0.67^{b}	6.00±0.58^{c}	10.33±0.64^{ab}
Plantain	11.66±0.33^{a}	10.33±0.88^{ab}	13.00±0.47^{a}
CV (%)	9.31	11.45	13.65

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

4.7. Effect of choice and no-choice food preference on emergence of F_1 progeny

The F_1 progeny emergence of *A. fasciculatus* was significantly different ($P<0.05$) from each other with respect to dried chip type. On no choice experiment Cassava produced the greatest number of F1 progeny (180.67) while the lowest mean of F_1 progeny was obtained in white yam (133.67) (Table 4.25). Length of F_1 progeny was higher on water yam (3.16 mm) but not significantly higher than cassava (2.97mm) and white yam (2.91mm) while the lowest mean was observed on plantain (2.40mm) and sweet potato (2.35mm). The highest width of F_1 progeny was observed on cassava (1.17mm) which was greater significantly ($P < 0.05$) than the width observed on the rest of the food hosts. There exists no difference in the width of *A. fasciculatus* reared on other food hosts; sweet potato (1.06mm), water yam (1.05mm), white yam (1.18mm) and plantain (1.03mm). The mean weight of F_1 progeny emerged was observed on cassava (2.60 mg), which has greater value than all other chips. This was followed by white yam (2.57mg) > water yam (2.48mg) > plantain (2.45mg), the lowest was recorded on sweet potato (2.45mg).

On free choice experiment the F_1 progeny was obtained in cassava (205) and plantain (180.67) was high while the lowest mean of F_1 progeny was obtained in white yam (133.67) (Table 4.26). Sweet potato (145.67), water yam (133.33) and white yam (144.00) had the same level of significant ($P < 0.05$). Length of F_1 progeny was higher on water yam (3.20mm), the least was observed on sweet potato (2.70mm). Mean width of F_1 progeny had the same level of significant ($P < 0.05$) on cassava (1.4mm), water yam (1.35mm) and white yam (1.32mm), the lowest width mean of F_1 progeny was obtained in sweet potato (1.02mm). The weight of F_1 progeny emerged was high significantly ($P < 0.05$) on cassava (2.7mg) and white yam (2.68mg) > water yam (2.62), the least was observed in plantain (2.53mg) and sweet potato (2.52). (Table 4.26).

4.8 Weight loss assessment of *Araecerus fasciculatus* on dried chips

The weight loss of dried chips in percentage as a result of the feeding of these weevils on them (Fig 4.8). Percentage weight loss is from a low of 16.60% to a high of 35.81%. The percentage weight loss varied significantly ($P < 0.05$) across the food hosts. Damage done to plantain (35.81%) was significantly higher than the damage inflicted on other crops.

Table 4.25. Effects of food hosts on developmental parameters (± S.E.) of F_1 progenies using Free Choice Experiment

Treatment	No of introduced insects	Mean of F_1 progeny emerged	Mean Length of F_1 progeny emerged	Mean width of F_1 progeny emerged	Mean weight of F_1 progeny emerged
Cassava	23	205.00 ± 4.04^{a}	3.10 ± 0.12^{ab}	1.4 ± 0.06^{a}	2.70 ± 0.03^{a}
Sweet potato	10	145.67 ± 3.48^{b}	2.70 ± 0.06^{c}	1.02 ± 0.01^{b}	2.52 ± 0.04^{b}
Water yam	16	133.33 ± 5.24^{b}	3.10 ± 0.08^{ab}	1.32 ± 0.04^{a}	2.62 ± 0.01^{ab}
White yam	15	144.00 ± 7.23^{b}	3.20 ± 0.04^{a}	1.35 ± 0.8^{a}	2.68 ± 0.04^{a}
Plantain	20	180.67 ± 8.69^{a}	2.88 ± 0.02^{bc}	1.21 ± 0.02^{ab}	2.53 ± 0.02^{b}
CV (%)		6.49	4.18	6.64	2.12

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Table 4.26. Effects of food hosts on developmental parameters (± S.E) of F_1 progenies using no choice experiment

Treatment	No of Introduced insects	Mean of F_1 progeny emerged	Mean Length of F_1 progeny emerged	Mean width of F_1 progeny emerged	Mean weight of F_1 progeny emerged
Cassava	10	180.67±5.20^{a}	2.97±0.04^{a}	1.17±0.12^{a}	2.60±0.03^{a}
Sweet potato	10	145.00±3.61^{c}	2.35±0.03^{b}	1.06±0.07^{b}	2.38±0.04^{c}
Water yam	10	143.33±6.12^{c}	3.16±0.07^{a}	1.05±0.04^{b}	2.48±0.01^{abc}
White yam	10	133.67±3.48^{c}	2.91±0.04^{a}	1.18±0.08^{b}	2.57±0.04^{ab}
Plantain	10	154.67±5.37^{b}	2.40±0.06^{b}	1.03±0.03^{b}	2.45±0.02^{bc}
CV(%)		5.57	3.42	2.81	2.27

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

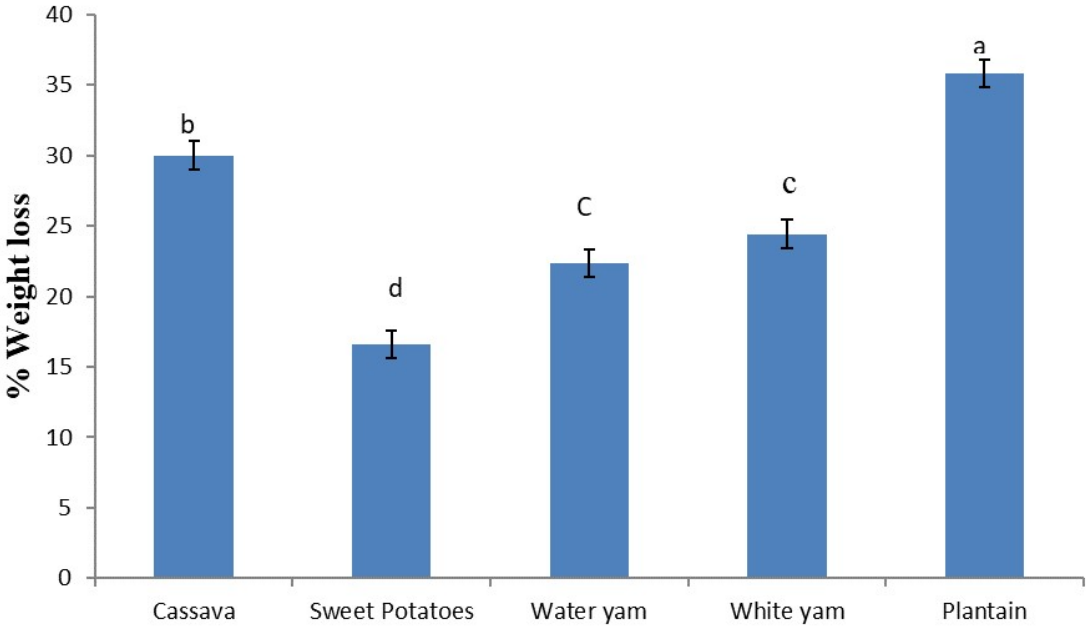


Figure 4.8: Percentage weight loss assessment of *Araecerus fasciculatus* on dried chips

Bars with the same letters are not significantly different using Tukey's HSD at α 0.05

Percent weight loss in water yam (22.37%) and white yam (24.43%) were not differed from each other. *A fasciculatus* inflicted a least percentage weight loss on sweet potato (16.60%).

4.9. Assessment of qualitative and quantitative damage by *Araecerus fasciculatus* on selected dried chips.

The percentage weight loss of the dried chips due to *A. fasciculatus* continuous activities on them (Table 4.27). It also showed definite preference for different dried chips. The percentage weight loss significantly ($P<0.05$) varied across the food hosts and the length of storage. Percentage damage by *Araecerus fasciculatus* on cassava was from a low of 9% to a high 44.38% length of storage, while percentage damage on sweet potato was from low of 9% to a high of 28.75%. Water yam has a percentage damage of 10.75% to a high of 38.75%, white yam has 10.63% to a high of 36.88% and plantain 13.25% to a high of 52.75%. Percentage damage on plantain was significantly higher (13.25%, 37.13%, 52.75%) across the dried chips and the length of storage, potato was the least susceptible (9.00±0.61, 15.63±1.20, 28.75±0.72), both across the dried chips and the length of storage (Table 4.27). After 30 days there exists no difference significantly on the level of damage on cassava, potato, white yam and water yam, (9.13±0.6, 9.00±0.6 10.63±0.5 and 10.75±0.6) however, plantain had the highest damage which differed statistically from cassava, potato and white yam but not from water yam.

Mean weight loss on selected dried chips due to *A. fasciculatus* infestation after 60 days revealed that plantain (37.13±1.1) recorded maximum weight loss, which was significantly higher than all other dried chips ($P < 0.05$). There was no difference statistically ($P > 0.05$) in the damages recorded on cassava, white yam and water yam (20.63±1.2, 21.5±0.7 and 21.5±0.7). Potato had the least weight loss (15.63±1.2). Percentage damage after 90 days of storage was significantly ($P < 0.05$) different among plantain, cassava, white yam, water yam and potato (52.75±0.8, 44.38±1.6, 38.75±0.7, 36.88±1.2 and 28.75±0.7). At 30 and 60 days the same trend was observed in frass weight obtained, the highest mean weight of frass was obtained on cassava (30 days: 33.75g, 60 days: 76.50g) and plantain (30 days: 33.25g, 60 days:

Table 4.27: Mean weight loss (%) ± S.E of selected dried chips after *Araecerus*. *fasciculatus* infestation

Treatment	% weight loss		
	30 Days	60 Days	90 Days
Cassava	9.13±0.60^{b}	20.63±1.20^{b}	44.38±1.60^{b}
Potato	9.00±0.60^{b}	15.63±1.20^{c}	28.75±0.70^{d}
Water Yam	10.75±0.60^{ab}	21.5±0.70^{b}	38.75±0.70^{c}
White Yam	10.63±0.50^{b}	23.5±0.90^{b}	36.88±1.20^{c}
Plantain	13.25±0.60^{a}	37.13±1.10^{a}	52.75±0.80^{a}
CV%	10.91	8.73	5.27

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Plate 4.2: Damaged dried chips caused by exit holes and feeding activities of *A. fasciculatus*

A: Dried chips showing damages caused by exit holes

B: Frass

83.75g), white yam (30 days: 25.75g, 60 days: 67.50g) and water yam (30 days: 27.25g, 60 days: 64.25g) had the same level of significant, the least frass weight at 30 and 60 days was produced on sweet potato (15.75g, 55.00g respectively). At 60 days the highest mean weight of frass was produced on cassava (111.75g) which was statistically higher than all other chips, this was followed by cassava (103.50g) > white yam (87.5g) > water yam (86.25g). The lowest frass was recorded on potato (78.75g) (Table 4.28).

Furthermore, proximate analysis (Table 4.29) indicated the effect of *A. fasciculatus* infestation on stored dried chips. Storage durations significantly influenced proximate parameters of the selected chips. At the beginning of storage period, there exists significant increase ($P < 0.05$) in amount of ash. Water yam, plantain and cassava (3.10±0.1a, 3.01±0.1, 2.80±0.1) (g/100 g) had the highest significant content of ash. At 90 days after storage, the ash content decreased and also varied significantly on all dried chips examined, plantain (2.70±0.2) was higher than other dried chips while cassava (0.82±0.1) (g/100 g) and white yam (1.67±0.4) (g/100 g) were not statistically different from one another, yet they were much lower than what was obtained on water yam (2.19±0.2) (g/100 g) and sweet potato (1.20±0.1) (g/100 g). At the beginning of storage period, crude protein level was not higher statistically ($P > 0.05$) on water yam, white yam, plantain and sweet potato (3.82±0.0, 3.62±0.5, 3.45±0.1, and 3.17±0.0) (g/100 g) respectively, while crude protein in cassava (1.62±0.1) (g/100 g) was the lowest. Different trend was observed in storage after 90 days, a substantial difference in crude protein was found (7.70±0.1, 5.20±0.1, 4.50±0.1, 3.80±0.1 and 1.90±0.1 (g/100 g) on water yam, white yam, potato, plantain and cassava respectively. When dried chips were stored for 3-month, storage period and feeding of insects on them significantly ($P < 0.05$) decreases the crude fibre and amount of dry matter. During storage, however, the quantity of crude protein, fat, and moisture increased statistically ($P < 0.05$) (Table 4.29).

Mineral content was significantly affected by storage and infestation duration (Table 4.30) of all the dried chips. After 3 months in storage, all the mineral content steadily decreased with continuous feeding of insect on them (Table 4.30).

Table 4.28: Weight of frass (g) ± S.E of *A. fasciculatus* infested dried chips

Treatment	Weight of frass		
	30 Days	60 Days	90 Days
Cassava	33.75±0.75[a]	76.50±2.03[a]	103.50 ±1.3[b]
Sweet potato	15.75±0.85[c]	55.00±1.23[c]	78.75 ±1.5[d]
Water yam	27.25±0.48[b]	64.25±1.0[b]	86.25 ±0.8[c]
White yam	25.75±0.48[b]	67.50±1.04[b]	87.5 ±1.04[c]
Plantain	33.25±0.48[a]	83.75±2.30[a]	111.75 ±2.7[a]
CV%	4.64	4.93	3.43

Tukey's HSD Test at α = 0.05 finds no significant differences between means within a column with the same letter(s)

Table 4.29: Effect of *A. fasciculatus* infestation on proximate composition of dried chips g/100 g

Treatment	Storage Duration	Ash	Crude Protein	Fat	Crude Fibre	Dry Matter
Cassava	0	2.80±0.10^{a}	1.62±0.10^{b}	1.20±0.20^{b}	2.50±0.10^{a}	93.00±0.10^{ab}
	90	0.82±0.10^{c}	1.90±0.10^{d}	1.26±0.20^{c}	2.00±0.10^{a}	82.50±0.00^{c}
Potato	0	1.73±0.10^{c}	3.17±0.00^{a}	1.98±0.60^{b}	1.70±0.10^{b}	93.50±0.00^{a}
	90	1.20±0.10^{bc}	4.50±0.10^{bc}	2.13±0.20^{ab}	1.30±0.10^{b}	92.70±0.10^{a}
Water Yam	0	3.10±0.10^{a}	3.62±0.50^{a}	2.10±0.10^{a}	1.80±0.10^{b}	92.50±0.10^{bc}
	90	2.19±0.20^{ab}	5.20±0.10^{b}	2.57±0.20^{a}	1.40±0.10^{b}	91.90±0.10^{ab}
White Yam	0	2.30±0.10^{b}	3.82±0.00^{a}	2.47±0.10^{a}	2.00±0.10^{b}	92.10±0.10^{c}
	90	1.67±0.40^{c}	7.70±0.10^{a}	2.73±0.10^{a}	1.70±0.10^{ab}	90.80±0.60^{b}
Plantain	0	3.01±0.10^{a}	3.45±0.10^{a}	1.37±0.10^{b}	1.90±0.20^{b}	93.10±0.10^{a}
	90	2.70±0.20^{a}	3.80±0.10^{c}	1.67±0.10^{bc}	1.60±0.10^{ab}	92.40±0.10^{a}

Tukey's HSD Test at α.= 0.05 finds no significant differences between means within a column with the same letter(s)

Table 4.30: Effect of *A. fasciculatus* infestation on mineral element of dried chips g/100 g

Treatment	Storage duration (days)	Calcium (Ca)	Potassium(K)	Iron (Fe)	Phosphorus(P)
Cassava	0	0.05 ± 0.00^{a}	1.82 ± 0.00^{a}	2.20 ± 0.10^{bc}	2.20 ± 0.00^{bc}
	90	0.04 ± 0.00^{a}	0.90 ± 0.10^{b}	2.10 ± 0.10^{a}	0.20 ± 0.00^{b}
Potato	0	0.05 ± 0.00^{a}	0.84 ± 0.00^{c}	2.38 ± 0.20^{b}	2.40 ± 0.10^{b}
	90	0.04 ± 0.00^{a}	0.70 ± 0.00^{b}	1.80 ± 0.10^{b}	0.20 ± 0.00^{b}
Water Yam	0	0.02 ± 0.00^{b}	1.45 ± 0.00^{b}	1.75 ± 0.10^{c}	1.80 ± 0.00^{c}
	90	0.02 ± 0.00^{c}	1.17 ± 0.00^{a}	0.80 ± 0.10^{c}	0.40 ± 0.00^{a}
White Yam	0	0.03 ± 0.00^{b}	1.00 ± 0.10^{c}	1.77 ± 0.10^{c}	1.80 ± 0.00^{bc}
	90	0.02 ± 0.00^{bc}	0.73 ± 0.10^{b}	1.00 ± 0.00^{c}	0.40 ± 0.00^{a}
Plantain	0	0.05 ± 0.00^{a}	0.90 ± 0.10^{c}	5.81 ± 0.10^{a}	5.80 ± 0.00^{a}
	90	0.04 ± 0.00^{ab}	0.73 ± 0.00^{b}	1.10 ± 0.00^{c}	0.20 ± 0.00^{b}

Tukey's HSD Test at α.= 0.05 finds no significant differences between means within a column with the same letter(s)

4.10. Efficacy of processing dried chips with fermented maize water and lime

Processing of chips with fermented maize water and lime significantly influenced ($P < 0.05$) insect developmental period, adult longevity and percentage chips damage (Fig 4.9 – Fig 4.11). On cassava, treatment T_4 had highest developmental period (70.00 ± 2.3 days) which was significantly higher than other treatments while treatment T_6 had the lowest developmental period (47.75 ± 0.6). Adult longevity recorded on treatment T_6 (80.25±4.1 days) was longer significantly than the remaining treatments while treatment T_4 had least adult longevity (31.75±1.2e days). The percentage damage was significantly higher in treatment T_6 (21.25±0.7) than the rest of the treatment while T_4 had the lowest percentage damage (0.63±0.1d) (Fig. 4.9).

On potato, treatment T_4 and T_3 had significant highest developmental period (59.75±2.1 and 54.5±1.85) than other treatments. Insect developmental period in treatments T_5, T_1 and T_2 (47.00±1.6, 49.25±0.5, 49.75±2.4 days) respectively were not statistically different from each other. Treatment T_6 had the lowest developmental period (45.50±1.4 days) (Fig. 4.9). Among the potato treated, T_6 (91.50±4.2 days) had the longest adult longevity while T_4 recorded the lowest (32.25±0.9 days) adult longevity (Fig. 4.10). On percentage damage, damage on T_6 treatment (15.63±1.2) was higher than the remaining treatment while statistical difference does not exists among the damage recorded on T_2, T_3 and T_4 (0.84±0.0, 0.56±0.1 and 0.34±0.1) respectively. (Fig. 4.11).

On water yam, there exists no difference significantly in developmental period among treatments T_2, T_3 and T_4 (72.75±1.1, 73.75±0.5 days and 77.00±0.9 days), but was different statistically from treatment T_6 (56.25±1.7). Adult longevity of coffee bean weevil was influenced by different treatment applications, with longest observed on treatment T_6 (105±3.9 days) and lowest on T_5 (33.75±0.8 days). The highest percentage damage was observed on T_6 (20.88±0.7) while damage on treatments T_2, (0.80±0.0), T_3 (0.50±0.1) and T_4 (0.38±0.1), were not significantly difference from one another (Fig. 4.11). It was observed on white yam that treatment T_4 (78.25±0.9 days) recorded highest developmental period but not significantly higher than treatment T_2 (74.00±0.7 days) and T_3

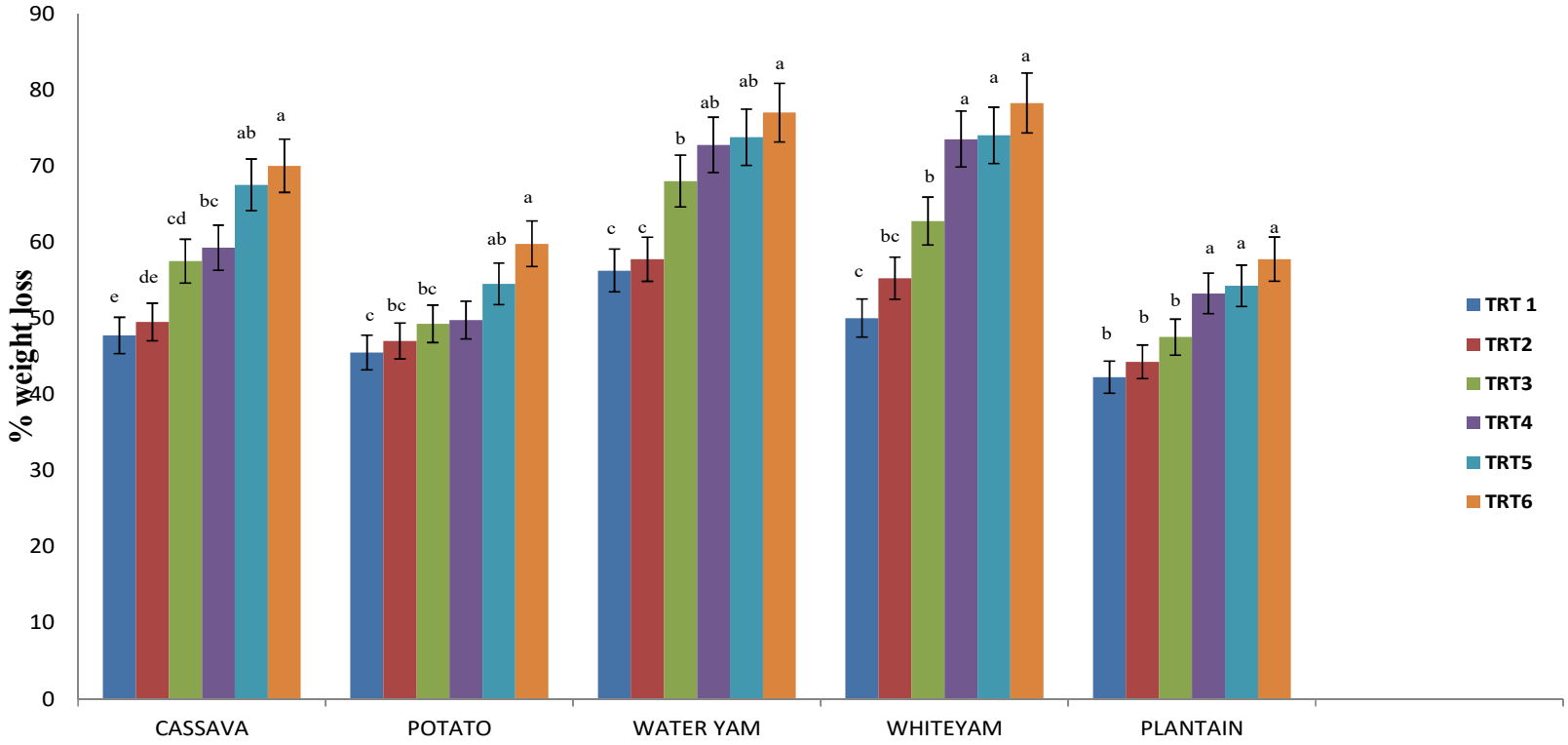


Fig. 4.9: Efficacy of the treatment of dried chips with fermented maize water and lime on the developmental period of *A. fasciculatus*

Bars with the same letters are not significantly different using Tukey's HSD Test at α.05

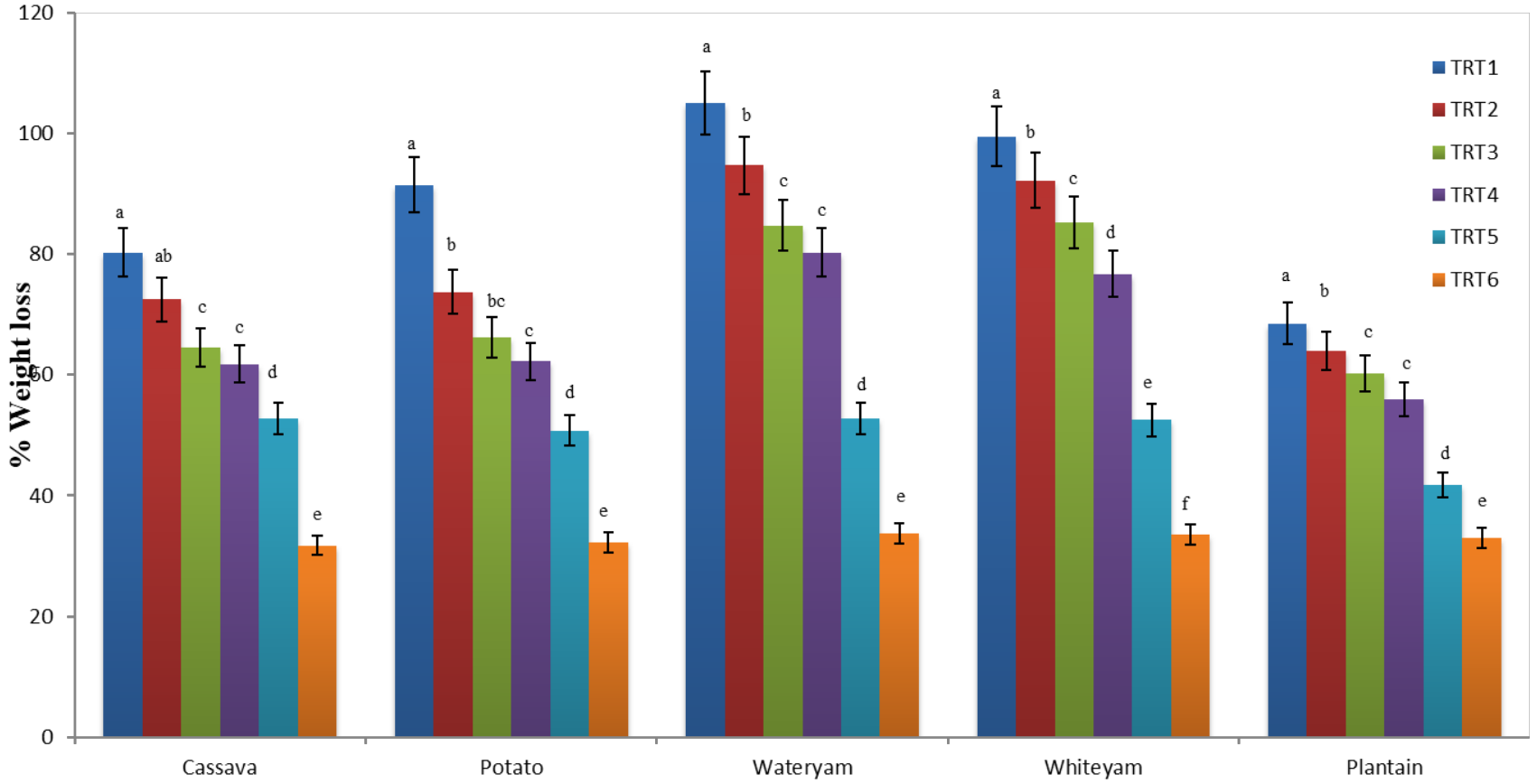


Figure 4.10: Efficacy of the treatment of dried chips with fermented maize water and lime on the adult longevity of *A. fasciculatus*

Bars with the same letters are not significantly different using Tukey's HSD Test at α.05

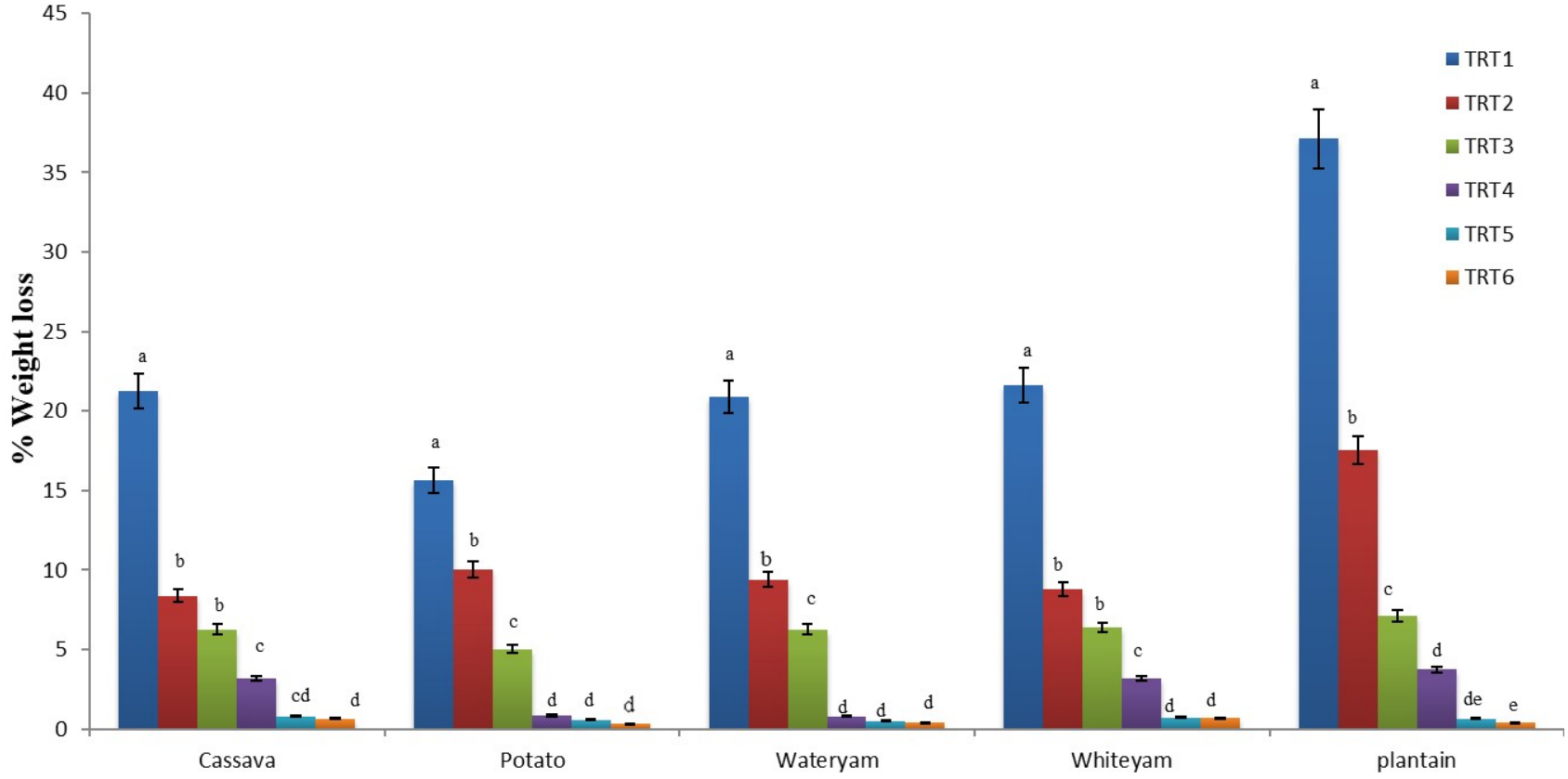


Fig. 4.11: Efficacy of the treatment of dried chips with fermented maize water and lime on the percentage damage of *A. fasciculatus*

Bars with the same letters are not significantly different at Tukey's HSD Test at α.05

(78.25±0.9 days), but the least developmental period was recorded on T_6 (50.00±3.1 days). Treatment greatly influenced adult longevity on white yam from 99.50±0.9 (T_6) days to 33.50±1.2 (T_4) days. Highest percentage damage was recorded on T_6 (21.61±0.6) and the least on T_4 (0.66±0.1) due to the influence of treatment on the dried chips (Fig. 4.11).

Treatment application of fermented maize water and lime on plantain had influence coffee bean weevil developmental period, adult longevity and damage assessment (Fig 4.9 – 4.11). T_4 (57.75±0.9) recorded highest developmental period. On treatments T_6, (42.25±1.9) T_5, (44.25±0.6) and T_1, (47.5±1.0), influence of treatment on developmental period were significantly the same. Adult longevity was higher in T_6 (68.50±1.3) and lowest on T_4 (33.00±1.1). Treatment applications greatly influenced percentage damage from a high of 37.13±1.1 (T_6) to a low of 0.38±0.1 (T_4). Effects of all treatment applications on percentage damage were significantly different from one another (Fig. 4.11).

4.11 Quantitative Phytochemical Composition of the Treated Samples

The phytochemical composition in the fermented maize water and lime treated samples varies among the treatments across all the selected dried chips. Table 4.31 shows the percentage phytochemical present in dried cassava chips had a higher significant level of tannin ($0.0022\pm5.8x10^{-05}$) in treatment T_4 than in T_5, T_1, T_2, T_6 and T_3 ($0.0015\pm3.3x10^{-05}$, $0.0015\pm3.3x10^{-05}$, $0.0016\pm3.3x10^{-05}$, $0.0016\pm3.3x10^{-05}$ and $0.0009\pm6.7x10^{-05}$) respectively. Similarly percentage saponin present in treatment T_4 ($0.2120\pm8.8x10^{-4}$) was higher statistically than treatment T_3 ($0.2067\pm5.8x10^{-4}$) but treatment T_2, T_1 and T_5 ($0.1993\pm5.8x10^{-4}$, $0.1973\pm5.8x10^{-4}$, $0.1967\pm5.8x10^{-4}$) respectively were not different statistically but has higher percentage of saponin than CA_1 ($0.1773\pm1.5x10^{-3}$) which has the least saponin percentage.

Furthermore, percentage of alkaloids and phenols were higher significantly in T_4 and T_3 ($0.0267\pm8.8x10^{-4}$ and $0.0307\pm8.8x10^{-4}$) respectively than the rest of the treatment. Generally, the higher the concentration of the treatment the higher the phytochemical present and saponin happened to be the highest phytochemical present in all the treatments. (Table 4. 31).

Table 4.31: Phytochemical composition of the treated dried cassava samples

Treatment	%Tannin	%Saponin	%Alkaloids	%Phenol
T_1	$0.0015\pm3.3x10^{-05b}$	$0.1973\pm5.8x10^{-4c}$	$0.0150\pm5.8x10^{-4cd}$	$0.0220\pm5.8x10^{-4bc}$
T_2	$0.0016\pm3.3x10^{-05b}$	$0.1993\pm5.8x10^{-4c}$	$0.0177\pm3.3x10^{-4bc}$	$0.0250\pm5.8x10^{-4cd}$
T_3	$0.0016\pm3.3x10^{-05b}$	$0.2067\pm5.8x10^{-4b}$	$0.0190\pm5.8x10^{-4b}$	$0.0270\pm5.8x10^{-4d}$
T_4	$0.0022\pm5.8x10^{-05a}$	$0.2120\pm8.8x10^{-4a}$	$0.0267\pm8.8x10^{-4a}$	$0.0307\pm8.8x10^{-4a}$
T_5	$0.0015\pm3.3x10^{-05b}$	$0.1967\pm5.8x10^{-4c}$	$0.0133\pm3.3x10^{-4d}$	$0.0207\pm8.8x10^{-4d}$
T_6	$0.0009\pm6.7x10^{-05c}$	$0.1773\pm1.5x10^{-3d}$	$0.0070\pm5.8x10^{-4e}$	$0.0113\pm6.7x10^{-4e}$

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s).

The result of the study conducted on treated dried potato samples reveals that the higher the amount of the treatments the higher the percentage of phytochemical present and saponin has highest percentage than the rest of the phytochemical. Treatment T_4 had a higher proportion of tannin, saponin, alkaloids and phenols ($0.0016\pm3.3x10^{-5}$, $0.1590\pm5.8x10^{-4}$, $0.0967\pm3.3x10^{-4}$ $0.1070\pm5.8x10^{-4}$) respectively than the rest of the treatment. Percentage tannin in T_5 ($0.0006\pm3.3x10^{-5}$) and PO_3 ($0.0007\pm3.3x10^{-5}$) were not different significantly. Percentage saponin, alkaloids and phenols in T_3, T_2, T_1, T_5 and T_6 respectively differ significantly (Table 4.32). The same trend was observed in water yam. Percentage of phytochemical in each treatment increases with increase in proportion of fermented maize water and lime in the treatment. In T_4, tannin ($0.0039\pm5.8x10^{-5}$) had higher statistical value than the rest of the treatment. Saponin in T_4 ($0.2120\pm5.8x10^{-4}$) was greater significantly than what was obtained in T_3 ($0.2067\pm3.3x10^{-4}$), but there exists no significant difference in percentage saponin of treatments T_2, T_1 and T_5 ($0.1993\pm8.8x10^{-4}$, $0.1973\pm3.3x10^{-4}$ and $0.1967\pm8.8x10^{-4}$) respectively. Percentage alkaloids in treatment T_4 ($0.1457\pm6.7x10^{-4}$) was statistically higher than what was obtained in T_3, T_2, T_1, T_5 and T_6 ($0.1450\pm5.8x10^{-4}$, $0.1420\pm5.8x10^{-4}$, $0.1380\pm5.8x10^{-4}$, $0.1340\pm5.8x10^{-4}$ and 0.1037 ± 8.8 $x10^{-4}$) respectively. Similarly, percentage phenol in water yam treatment T_4 ($0.1333\pm8.8x10^{-4}$) was significantly higher than what was obtained in T_3, T_2, T_1, T_5 and T_6 ($0.1300\pm5.8x10^{-4}$, $0.1283\pm3.3x10^{-4}$, $0.1260\pm5.8x10^{-4}$, $0.1240\pm5.8x10^{-4}$ and $0.0876\pm1.3x10^{-3}$). (Table 4. 33)

In Table 4.34 percentage of phytochemical in each white yam treatment increases with increase in quantity of the treatment. Tannin in T_4 and T_3 ($0.0030\pm3.3x10^{-5}$ and $0.0028\pm8.8x10^{-5}$) had the same significant, greater significantly than tannin in T_2 and T_1 ($0.0023\pm5.8x10^{-5}$ and $0.0021\pm8.8x10^{-}$). Percentage saponin in T_6 ($0.1800\pm5.8x10^{-4}$) was higher than T_3, T_2, T_1, T_5 and T_6 ($0.1720\pm5.8x10^{-4}$, $0.1720\pm5.8x10^{-4}$, $0.1300\pm5.8x10^{-4}$, $0.1160\pm5.8x10^{-4}$ and $0.0873\pm1.2x10^{-3}$) respectively. Percentage alkaloid in T_4 ($0.1270\pm5.8x10^{-4}$) was also greater than what were obtained in T_3, T_2, T_1, T_5 and T_6 ($0.1240\pm5.8x10^{-4}$, $0.1200\pm1.0x10^{-3}$, $0.1160\pm5.8x10^{-4}$, $0.1133\pm3.3x10^{-4}$ and $0.1123\pm3.3x10^{-4}$) respectively. Similarly, percentage phenol in WH_6 ($0.1207\pm8.8x10^{-4}$) was statistically higher than what were obtained in T_3, T_2, T_1, T_5 and T_6 ($0.1180\pm5.8x10^{-4}$, $0.1140\pm5.8x10^{-4}$, $0.1053\pm1.5x10^{-3}$, $0.0967\pm8.8x10^{-4}$ and $0.0870\pm1.2x10^{-3}$) respectively. (Table 4.34)

Table 4.32: Phytochemical composition of the treated dried potato samples

Treatment	%Tannin	%Saponin	%Alkaloids	%Phenol
T_1	$0.0007\pm3.3\times10^{-5d}$	$0.1270\pm5.8\times10^{-4d}$	$0.0283\pm3.3\times10^{-4d}$	$0.0513\pm3.3\times10^{-4d}$
T_2	$0.0009\pm3.3\times10^{-5c}$	$0.1470\pm5.8\times10^{-4c}$	$0.0673\pm3.3\times10^{-4c}$	$0.0983\pm3.3\times10^{-4c}$
T_3	$0.0011\pm3.3\times10^{-5b}$	$0.1537\pm8.8\times10^{-4b}$	$0.0853\pm3.3\times10^{-4b}$	$0.1033\pm8.8\times10^{-4b}$
T_4	$0.0016\pm3.3\times10^{-5a}$	$0.1590\pm5.8\times10^{-4a}$	$0.0967\pm3.3\times10^{-4a}$	$0.1070\pm5.8\times10^{-4a}$
T_5	$0.0006\pm3.3\times10^{-5d}$	$0.1213\pm3.3\times10^{-4e}$	$0.0233\pm3.3\times10^{-4e}$	$0.0353\pm6.7\times10^{-4e}$
T_6	$0.0004\pm3.3\times10^{-5e}$	$0.1063\pm8.8\times10^{-4f}$	$0.0153\pm3.3\times10^{-4f}$	$0.0226\pm6.7\times10^{-4f}$

Tukey's HSD Test at $\alpha.= 0.05$ finds no significant differences between means within a column with the same letter(s)

Table 4.33: Phytochemical composition of the treated dried water yam samples

Treatment	%Tannin	%Saponin	%Alkaloids	%Phenol
T_1	$0.0033\pm3.3x10^{-5cd}$	$0.1973\pm3.3x10^{-4c}$	$0.1380\pm5.8x10^{-4c}$	$0.1260\pm5.8x10^{-4cd}$
T_2	$0.0034\pm3.3x10^{-5bc}$	$0.1993\pm8.8x10^{-4c}$	$0.1420\pm5.8x10^{-4}{}_b$	$0.1283\pm3.3x10^{-4bc}$
T_3	$0.0036\pm3.3x10^{-5b}$	$0.2067\pm3.3x10^{-4b}$	$0.1450\pm5.8x10^{-4ab}$	$0.1300\pm5.8x10^{-4ab}$
T_4	$0.0039\pm5.8x10^{-5a}$	$0.2120\pm5.8x10^{-4a}$	$0.1457\pm6.7\ x10^{-4a}$	$0.1333\pm8.8x10^{-4a}$
T_5	$0.0032\pm3.3x10^{-5d}$	$0.1967\pm8.8x10^{-4c}$	$0.1340\pm5.8x10^{-4d}$	$0.1240\pm5.8x10^{-4d}$
T_6	$0.0022\pm5.8x10^{-05e}$	$0.1773\pm1.2x10^{-3d}$	$0.1037\pm8.8\ x10^{-4e}$	$0.0876\pm1.3x10^{-3e}$

Tukey's HSD Test at α.= 0.05 finds no significant differences between means within a column with the same letter(s)

Table 4.34: Phytochemical composition of the treated dried white yam samples

Treatment	%Tannin	%Saponin	%Alkaloids	%Phenol
T_1	$0.0021\pm8.8\times10^{-5b}$	$0.1300\pm5.8\times10^{-4d}$	$0.1160\pm5.8\times10^{-4d}$	$0.1053\pm1.5\times10^{-3c}$
T_2	$0.0023\pm5.8\times10^{-5b}$	$0.1630\pm5.8\times10^{-4c}$	$0.1200c\pm1.0\times10^{-3c}$	$0.1140\pm5.8\times10^{-4b}$
T_3	$0.0028\pm8.8\times10^{-5a}$	$0.1720\pm5.8\times10^{-4b}$	$0.1240b\pm5.8\times10^{-4b}$	$0.1180\pm5.8\times10^{-4ab}$
T_4	$0.0030\pm3.3\times10^{-5a}$	$0.1800\pm5.8\times10^{-4a}$	$0.1270a\pm5.8\times10^{-4a}$	$0.1207\pm8.8\times10^{-4a}$
T_5	$0.0010\pm5.8\times10^{-5c}$	$0.1160\pm5.8\times10^{-4e}$	$0.1133\pm3.3\times10^{-4de}$	$0.0967\pm8.8\times10^{-4d}$
T_6	$0.0006\pm3.3\times10^{-5d}$	$0.0873\pm1.2\times10^{-3f}$	$0.1123\pm3.3\times10^{-4e}$	$0.0870\pm1.2\times10^{-3e}$

Tukey's HSD Test at $\alpha.= 0.05$ finds no significant differences between means within a column with the same letter(s)

The percentage phytochemical present in dried plantain chips which had a higher level of tannin ($0.0030\pm6.7x10^{-5}$) in T_4 than ($0.0025\pm8.8x10^{-5}$) present in T_3. Tannin in T_1, and T_2 ($0.0019\pm8.8x10^{-5}$ and $0.0022\pm5.8x10^{-5}$) respectively were the same statistically but were statistically greater than what were obtained in T_5 (Table 4.35), ($0.0016\pm5.8x10^{-5}$) and T_6 ($0.0008\pm3.3x10^{-5}$). Percentage saponin present in T_4 ($0.1930\pm5.8x10^{-4}$) was greater than what were present in T_3, T_2, T_1, T_5 and T_6 ($0.1680\pm5.8x10^{-4}$, $0.1650\pm5.8x10^{-4}$, $0.1620\pm5.8x10^{-4}$, $0.156\pm5.8x10^{-4}$ and $0.131\pm5.8x10^{-4}$). Furthermore, percentage alkaloids were significantly higher in T_4 ($0.1317\pm6.7\ x10^{-4}$) than T_3 ($0.1240\pm5.8x10^{-4}$) and T_2 ($0.1220\pm5.8x10^{-4}$). Treatment T_1, T_5 and T_6 ($0.1170\pm5.8x10^{-4}$, $0.1040\pm5.8x10^{-4}$ and $0.1010\pm5.8x10^{-4}$) statistically different from each another. Percentage phenols present in T_4 and T_3 ($0.1233\pm6.7x10^{-4}$ and $0.1220\pm5.8x10^{-4}$) were not different significantly ($P > 0.05$) but were statistically higher than what was obtained in T_2 ($0.1163\pm8.8x10^{-4}$). Percentage tannin in T_1 ($0.114b\pm5.8x10^{-4}$) and T_5 ($0.1107\pm8.8x10^{-4}$) had the same level of significance (Table 4.35).

4.12. Influence of Treatment on Organoleptic Properties of Selected Dried Chips (Amala)

Sensory evaluation conducted on all the treated dried chips reveals there had been no significant changes on all the parameter tested, that is, application of fermented maize water and lime did not have effect on the taste, colour, smoothness, elasticity, viscosity, odour, stickness and overall acceptance of cassava, potato, water yam, white yam and plantain (Table 36 - 40).

Table 4.35: Phytochemical composition of the treated dried plantain samples

Treatment	%Tannin	%Saponin	%Alkaloids	%Phenol
T_1	$0.0019 \pm 8.8 \times 10^{-5c}$	$0.1620 \pm 5.8 \times 10^{-4d}$	$0.1170 \pm 5.8 \times 10^{-4c}$	$0.114b \pm 5.8 \times 10^{-4c}$
T_2	$0.0022 \pm 5.8 \times 10^{-5c}$	$0.1650 \pm 5.8 \times 10^{-4c}$	$0.1220 \pm 5.8 \times 10^{-4b}$	$0.1163 \pm 8.8 \times 10^{-4b}$
T_3	$0.0025 \pm 8.8 \times 10^{-5b}$	$0.1680 \pm 5.8 \times 10^{-4b}$	$0.1240 \pm 5.8 \times 10^{-4b}$	$0.1220 \pm 5.8 \times 10^{-4a}$
T_4	$0.0030 \pm 6.7 \times 10^{-5a}$	$0.1930 \pm 5.8 \times 10^{-4a}$	$0.1317 \pm 6.7 \times 10^{-4a}$	$0.1233 \pm 6.7 \times 10^{-4a}$
T_5	$0.0016 \pm 5.8 \times 10^{-5d}$	$0.156 \pm 5.8 \times 10^{-4e}$	$0.1040 \pm 5.8 \times 10^{-4d}$	$0.1107 \pm 8.8 \times 10^{-4c}$
T_6	$0.0008 \pm 3.3 \times 10^{-5e}$	$0.131 \pm 5.8 \times 10^{-4f}$	$0.1010 \pm 5.8 \times 10^{-4e}$	$0.073 \pm 1.0 \times 10^{-3d}$

Tukey's HSD Test at $\alpha = 0.05$ finds no significant differences between means within a column with the same letter(s)

Plate 4.3: Sensory Evaluation test of the treated chips by selected trained evaluators in the Department of Crop Protection and Environmental Biology, University of Ibadan.

Table 4.36: Sensory evaluation of treated cassava chips (Amala)

Treatments	**Taste (ns)**	**Colour (ns)**	**Smoothness (ns)**	**Elasticity (ns)**	**Viscosity (ns)**	**Odour (ns)**	**Stickiness (ns)**	**Overall acceptance (ns)**
T_1	4.33±0.88	3.00±0.58	5.67±0.88	5.33±0.88	4.33±0.33	5.00±c	4.00±0.88	4.33±1.20
T_2	4.67±0.88	4.33±1.20	5.00±1.00	3.67±0.33	3.67±0.33	5.00±0.58	4.00±0.88	4.33±0.33
T_3	5.00±0.58	5.00±0.57	6.00±1.00	5.67±0.88	4.00±0.57	5.00±1.00	4.33±0.67	5.67±0.33
T_4	4.33±1.33	6.33±0.33	6.00±0.00	5.00±0.57	4.33±0.88	5.00±1.00	4.33±0.88	4.33±0.67
T_5	4.33±0.33	3.67±0.20	5.00±1.00	4.67±0.88	5.33±0.88	5.00±1,16	3.67±0.33	4.67±0.33
T_6	4.33±0.88	4.33±0.88	5.00±0.58	4.33±1.20	4.33±0.88	4.67±0.66	4.00±0.88	4.67±0.67

* The results are the averages of three observations.
Rating scale of 1-7, where 1 = very poor, 2 = moderately poor, 3 = slightly poor, 4 = Moderate, 5 = moderately better, 6 = much better, 7 = extremely good

Table 4.37: Sensory evaluation of treated potato chips (Amala)

Treatments	Taste (ns)	Colour (ns)	Smoothness (ns)	Elasticity (ns)	Viscosity (ns)	Odour (ns)	Stickiness (ns)	Overall acceptance (ns)
T_1	6.00±1.00	6.00±0.58	6.67±0.33	5.67±0.67	6.33±0.67	6.67±0.33	5.00±1.16	4.33±1.20
T_2	6.00±0.58	6.00±0.58	6.33±0.33	5.33±0.33	5.67±0.33	6.33±0.33	4.33±0.33	4.33±0.33
T_3	6.33±0.33	6.00±1.00	6.33±0.33	5.33±0.33	5.67±0.33	6.33±0.67	4.67±0.33	5.67±0.33
T_4	6.33±0.67	6.00±0.58	6.33±0.33	5.33±0.88	5.67±0.67	6.33±0.33	5.33±0.66	4.33±0.67
T_5	6.00±0.58	6.00±0.58	6.33±0.33	5.33±0.88	6.00±0.58	6.33±0.33	3.00±0.58	4.67±0.33
T_6	6.00±1.00	6.67±0.33	6.67±0.33	5.33±0.33	6.00±0.58	6.67±0.33	3.67±0.88	4.67±0.67

* The results are the averages of three observations.
Rating scale of 1-7, where 1 = very poor, 2 = moderately poor, 3 = slightly poor, 4 = Moderate, 5 = moderately better, 6 = much better, 7 = extremely good

Table 4.38: Sensory evaluation of treated water yam chips (Amala)

Treatments	Taste (ns)	Colour (ns)	Smoothness (ns)	Elasticity (ns)	Viscosity (ns)	Odour (ns)	Stickiness (ns)	Overall acceptance (ns)
T_1	3.00±1.16	3.66±0.33	5.33±0.67	4.66±0.33	3.33±1.20	5.00±0.57	3.00±0.00	4.33±1.20
T_2	3.33±0.67	3.66±0.88	5.00±1.00	4.33±0.33	3.33±0.33	5.00±0.57	3.00±0.57	4.33±0.33
T_3	3.00±0.00	3.66±0.67	5.00±1.00	4.66±0.67	3.33±0.33	5.00±0.57	2.67±0.67	4.33±0.67
T_4	3.33±0.33	3.66±0.67	5.33±0.33	4.66±0.33	3.00±0.00	5.00±0.57	3.33±0.67	4.33±0.67
T_5	3.33±1.20	3.33±0.67	5.00±1.00	4.66±0.88	30.33.33±	5.00±0.57	2.67±0.33	4.33±0.33
T_6	3.33±0.67	3.66±0.33	5.00±0.58	4.33±1.20	3.33±0.33	4.67±0.67	3.00±0.57	4.33±0.33

* The results are the averages of three observations.
Rating scale of 1-7, where 1 = very poor, 2 = moderately poor, 3 = slightly poor, 4 = Moderate, 5 = moderately better, 6 = much better, 7 = extremely good

Table 4.39: Sensory evaluation of treated white yam chips (Amala)

Treatments	Taste (ns)	Colour (ns)	Smoothness (ns)	Elasticity (ns)	Viscosity (ns)	Odour (ns)	Stickiness (ns)	Overall acceptance (ns)
T_1	4.67±0.33	4.67±0.67	5.00±0.58	4.33±0.33	6.00±0.58	5.33±0.67	4.67±0.88	4.33±0.33
T_2	5.00±0.33	4.67±0.33	5.00±1.00	4.33±0.33	5.67±0.33	4.67±0.33	5.00±0.57	4.33±0.33
T_3	5.00±0.67	4.67±0.33	4.67±0.33	4.67±0.33	5.67±0.67	5.00±1.00	5.00±0.00	4.33±0.67
T_4	4.67±1.20	5.00±0.33	5.00±0.58	4.33±0.33	6.00±0.58	5.00±0.58	4.67±0.33	4.33±0.67
T_5	5.00±0.58	4.33±1.20	5.00±1.00	4.67±0.88	6.00±0.58	5.00±0.58	4.67±0.67	4.33±1.20
T_6	4.67±0.33	4.33±0.33	4.67±0.33	4.33±1.20	6.00±0.00	4.67±0.67	5.00±0.57	4.33±0.33

* The results are the averages of three observations.
Rating scale of 1-7, where 1 = very poor, 2 = moderately poor, 3 = slightly poor, 4 = Moderate, 5 = moderately better, 6 = much better, 7 = extremely good

Table 4.40: Sensory evaluation of treated plantain chips (Amala)

Treatments	Taste (ns)	Colour (ns)	Smoothness (ns)	Elasticity (ns)	Viscosity (ns)	Odour (ns)	Stickiness (ns)	Overall acceptance (ns)
T_1	4.67±0.67	4.00±0.57	3.67±0.33	4.33±0.33	5.33±0.33	4.67±0.67	3.33±0.33	5.33±0.33
T_2	5.00±0.00	4.33±1.20	3.67±0.33	4.00±0.00	5.67±0.88	4.67±0.33	3.33±0.67	5.00±0.58
T_3	4.67±0.67	4.00±0.57	4.00±0.57	4.33±0.88	5.33±0.33	5.00±1.00	3.00±0.58	5.33±0.67
T_4	3.67±0.67	3.67±0.33	3.67±0.33	4.33±0.33	5.67±0.88	5.33±0.33	3.33±0.33	5.33±0.33
T_5	5.00±0.57	4.00±1.15	4.00±0.57	4.33±0.67	5.33±0.33	5.00±0.58	3.00±0.58	5.00±0.58
T_6	4.67±0.33	3.67±0.33	3.67±0.33	4.00±1.00	5.67±0.33	4.67±0.67	3.00±0.58	5.00±0.58

* The results are the averages of three observations.
Rating scale of 1-7, where 1 = very poor, 2 = moderately poor, 3 = slightly poor, 4 = Moderate, 5 = moderately better, 6 = much better, 7 = extremely good

CHAPTER FIVE

DISCUSSION

Insect occurrence, abundance and diversity studied showed that coleopterans and hymenopteran wasps were the prevailing orders found on all the selected dried chips. The coleopterans were the most abundant on all the dried chips, eight coleopterans species were found on the selected dried chips, as a result, they are the most diversified family and order, this corroborates the findings of Chalmers (1983) that coleopterans are the main orders of insect pests associated with dried chips. The genus *Sitophilus*, *Ryzopertha*, *Tribolium*, *Araecerus*, *Prostephanus*, *Callosobruchus*, *Lasioderma* and *Dinoderus* were found to be the predominant coleopterans. This was similar with Agona's (1995) and Nukenine *et al* (2002) findings, they observed those insects as economic storage insects pests in the tropics. Also, this study revealed that *Theocolax elegans* and *Cephalonomia waterstoni* as the predominant natural enemies associated with storage insects pest, this support the findings of Markham (1981) who reported them as natural enemies of insects associated with dried chips of yam.

There were variations in the diversity of insect from selected locations. There are less competition between insects species for those with rich diversity and those with low diversity indicates that there were much competition which has reduced the survival of insect species. Individual insects showed the number of specie present in the selected locations. Shannon's biodiversity index indicated low diversity due to the competition between the insect species. The Simpson's index (D) across the locations also showed varied value on cassava, water yam and white yam potato and plantain, it indicated moderate insect's diversity value on the first and somewhat low insects' diversity on the later. The evenness index across the locations for two-years survey on cassava, water yam and white yam potato and plantain indicated that the distribution of the insects are uniform. Margalef's index on cassava, water yam and white yam potato and plantain indicated species richness on cassava, water yam and white yam, because the

higher the insect population the higher the Margalef's index, meaning that the lower insect population on potato and plantain was responsible for their low Margalef's index. It was observed that insects were present in abundance on cassava, water yam and white yam across the locations because they had the best habitats and food materials for survival, as well as abundance of insects that are associated with them. The dominant insect across all dried chips was *Araecerus fasciculatus* and *Dinoderus minutus* which were found on all the dried chips: cassava, potato, water yam, white yam and plantain. *Araecerus fasciculatus* was most abundant species. This is consistent with Agona's (1995) results that *A. fasciculatus* is an important pest of stored produce and its infestation is manifested by circular perforation of dried chips, reduce flour content, presence of frass, and cast skin of dead insects.

The present study on pesticide residue limit established the presence of organochlorine pesticide residues in dried cassava and white yam chips sampled from selected locations in Nigeria. The average residual amounts in dried cassava and yam chips were both over the maximum residue limit (MRL) for the food products. The highest amount residue found in dried cassava and white yam chips was greater than EU's maximum residue limits, indicating that in all the samples analyzed, their percentage of OC residue were far above MRL.

The most predominant residue in dried cassava chips from all the locations was Methoxychlor while the least concentration was P,P1 DDT. The high Methoxychlor residues in dried cassava chips sampled indicated that one of the most often used pesticides contained methoxychlor as the active component for dried cassava chips pest management. The high percentage of Methoxychlor residues amount in cassava was probably as a result of crop's growing on polluted soils where application of the pesticides was severe or either as a result of previous use, causing bioaccumulation or its usage during processing and storage to protect it from insect infestation. This observation is similar to the research of Olufade *et al*., (2014) and Ogah *et al*., (2011) that 96% of the markets samples of dried chips in Southern Nigeria comprised one or more organochlorine pesticide residues.

Hence, P,P1 DDT was the most common residue found in dried yam chips from Ibadan and Saki markets and Methoxychlor from Osogbo market. This finding also suggested that these two OC

chemicals are active components in commonly used pesticides for the control of yam and dried yam chip pests. This supported the finding of Bempah *et. al*., (2012) and Essumang *et. al*., (2013) who reported persistence use of pesticide in some developing countries by farmers despite been banned in most countries. Lankondjoa et. al., (2016**)** observed that most farmers in underdeveloped nations are uneducated, and they are unaware of the damaging impacts of pesticides on the environment. To discourage and enable widespread acceptance of the regulation tests in this regard, a more realistic understanding of the pesticides detrimental effects on health and the environment is required, and it must be regularly applied among the developing countries' farmer population. It also advocates for improved pesticide sales control, farmer education and the deployment of combine pest management approaches.

The developmental biology of *A. fasciculatus* varied with respect to the food hosts. *Araecerus fasciculatus* had seven life stages comprising of egg, four larval instars, prepupa/pupa and adult. There was variation in the description and development biology of *A fasciculatus* reared on different dried chips. Oviposition began 6 to 7 days after emergence and lasted till 23rd days, the food host influenced the oviposition period of *A fasciculatus*, it had a longer oviposition period on white yam, cassava and water yam (16.5, 15.5, and 15.3 days) than on plantain and potato (14.8 and 12.5days) respectively, This is in agreement with Saheed (1935) findings that larva emergence of *A. fasciculatus* depends on the preference of the food host.

Copulation started 4 to 6 days after emergence. Eggs were laid immediately after mating. Mating occurred at both night and day, mating period ranged between 2 to 12 minutes, coffee bean weevil reared on white yam had a longer period of engagement (8.5 minutes), the lowest was recorded on sweet potato (6 minutes) while on water yam, cassava and plantain, time taken was 6.8, 6.8 and 7.3 minutes respectively. The incubation period of 3 to 7 days discovered on all dried chips in this study is related to the report of Saheed (1935) who observed an incubation period of 5-8 days on *A. fasciculatus*. Among the dried chips, the total average of eggs laid differed, 100 on white yam, 93 on water yam while fecundity on potato, cassava and plantain was 52.5, 61.5 and 58 respectively. Adult longevity recorded on different chips used were 88.5 days, 91.5 days, 105 days, 99.5 days and 66.5 days on cassava, potato, water yam, white yam and plantain. Total larva

developmental period was 19 - 29 days and pupa 2 - 4 days on all the dried chips used. This agrees with the study conducted by Saheed (1935) and Robert (1972) which shows that there were variations in adult longevity of *A. fasciculatus* studied on different food host. However, the findings are in accordance to the report of Ardakani and Nasserzadeh (2014) which stated that female *A. fasciculatus* laid about 60 eggs and the larva emerges in about 5 to 20 days. The findings was also in accordance with the report of Rees (2007) who reported that *A. fasciculatus* had a relatively short life cycle of about 66 days.

The frequency distribution of head capsule width of the larvae of *A. fasciculatus* studied on cassava, potato, water yam, white yam and plantain shows four larval instars. The developmental growth ratio observed from larva I to larva II on cassava, potato, water yam, white yam, plantain was higher than the one observed on larva II to III and larva III to IV respectively, the growth ratio decreases as larva instar increases, with mean growth ratio of 1.5 on all the dried chips studied. It shows the conformity of the head capsule measurement to Dyar's rule. The regular relationship of the larval vertex width and the significant regression coefficient for larval instars reared on cassava, potato, water yam, white yam and plantain respectively indicating there was no stadium ignored during the study. So, *A. fasciculatus* comprises of seven life stages comprises of egg, larva I, larva II, Larva III, Larva IV, pupa and adult. The findings is similar to the report of Alba-Alejandre *et al*. (2018) who confirmed that the coffee bean weevil has five instars, which can be distinguished by the width of the cephalic capsule.

Araecerus fasciculatus developmental period of F_1 was 40-55 days, 37-55 days, 35-60 days, 33-57 days and 36-52 days on cassava, potato, water yam, white yam and plantain respectively, with the male mean length of 3.89 mm, 2.88 mm, 2.74 mm, 3.89 mm and 2.85 mm, width of 1.28 mm, 1.07mm, 1.06 mm, 1.28 mm, and 1.07 mm on cassava, potato, water yam, white yam and plantain, respectively and female mean length of 4.88 mm, 3.79 mm, 3.75 mm, 4.85 mm and 4.59 mm, width of 1.21 mm, 1.63 mm, 1.08 mm, 1.43 mm and 1.30 mm respectively. This corroborates with findings of Cotton, (1921) and Saheed, (1935), they reported 42-57 days for *A fasciculatus* to develop and body length range from 2.5- 5mm. Length of *A. fasciculatus* pupa studied was 3.83mm, 3.88mm, 3.87mm, 3.82mm and 3.86mm, width of 1.85, 1.86, 1.94, 1.76 and

1.79 respectively on cassava, potato, water yam, white yam and plantain, similar result was found out by Cotton (1921), who reported 3.75mm-4mm pupa length and 2mm pupa width.

The food host preference study showed that *A. fasciculatus* prefered cassava and plantain to water yam, white yam. Potato was the least preferred host. The reason for this could be attributed to their composition and physical texture in comparison to other dried chips. This result corraborated the findings of Papadopoulos (2006) who repoted high susceptibility of cassava and potato to insect infestation. The study also showed high numbers of F_1 progeny emerged, weight of F_1, width of F_1 and significant weight loss could be because of the tenderness and smoothness of the dried cassava and plantain chips. This agrees with the report of Haines (1991)., whose findings said that the increased moisture level of the dried chips before drying may have caused cassava and plantain dried chips to ferment during sun drying, allowing the beetle to tunnel easily. Thus, cassava and plantain provided a suitable food source for insect to perform their activities.

Araecerus fasciculatus was able to bore into all the dried chips and reduced the quality because of the presence of exit holes, confirming its polyphagous status. These agrees with the reports of various researchers; Siswanto (1987) reported that *A. fasciculatus* was able to bore into nutmeg seeds and caused significant reduction in the quality of the seeds. Abo and Ja (2014) reported that *A. fasciculatus* was able to bore holes into yam and cassava. Eduku (2014) also reported *A. fasciculatus* caused significant damage on cocoa beans in storage. These findings also corroborates the reports of Hill (1990) who reported ability of *A. fasciculatus* to pierce, burrow, and grow on many food hosts, as well as its potential to inflict significant damage to dry chips during longer periods of infestation.

The feeding activities of *A. fasciculatus* caused significant weight loss on all the dried chips. It was also noted that *A. fasciculatus* preferred cassava and plantain. After 90 days of infestation, percentage weight loss was highest on plantain (52.75%) > cassava (44.38%) > water yam (38.75%) > white yam (36.88%). The least weight loss was recorded on sweet potatoes (28.75%). This corroborates the findings of Danjuma (2002) who reported that *A.*

fasciculatus caused a weight loss of above 40% in cassava products after 90 days of infestation.

The ability of *A. fasciculatus* to feed on different food substrates corroborate the findings of Jordan (1945) and Merdelyn *et al*. (2011), which described coffee bean weevil as primary pest of stored product that generally infests a wide variety of dry materials. The result is similar with the findings of Isah (2012) who discovered that *Prostephanus truncatus* was able to penetrate potato and cassava and causes higher percentage loss than other food materials used. The preference which led to higher loss of cassava and potato might be due to the composition and physical texture of the dried chips which facilitates the higher infestation of the insects, researcher like Papadopoulos (2006) and Kohno *et.al*., (1986), have reported the susceptibility of cassava and potato to insect infestation. The mean weight of frass produced by *A. fasciculatus* after 30, 60 and 90 days respectively varied among the dried chips. Insects reared on plantain chips (33.25g, 83.75g and 111.75g) respectively and cassava (33.75g, 76.50g and 103.50g) respectively produced the greatest amount of frass, whereas the lowest amount of frass was recorded on sweet potato chips (15.75g, 55g and 78.75g) respectively.

There were considerably reductions in the level of proximate contents of the chips before and after *A. fasciculatus* infestation for 90 days. Total protein, moisture contents and fats contents increases, but ash contents, crude fibre and dry matter decreases after *A. fasciculatus* infestation this is similar with the reports of Babarinde *et al*. (2010) who reported that Tribolium castaneum infestation causes physical and biophysical damage of stored plantain chips (Musa sapientum L.) and also corroborate the findings of Chijindu (2008) who reported that Araecerus fasciculatus prefers and damages processed cassava chips.. Mineral contents greatly decreased after 90 days of infestation by *A. fasciculatus.* This agrees with the report of Rajamma *et. al.,* (1996) and Chijindu (2008) who reported that stored products insect causes significant qualitative losses.

Study conducted on efficacy of blanching chips with fermented maize water and lime proved to be active by extending the developmental period of *A. fasciculatus*, reducing adult longevity and percentage damage recorded on different treated chips. This agrees the report of Nwana and Azodeh (1984) who on the amount of damage done to blanched yam chips before drying by the

coffee bean weevil. The same trend of result was observed in all the parameter tested. Developmental period on all the dried chips took the same trend, which indicated that treatment six (6) which had highest percentage of lime (10ml) was the most effective result. These treatments retarded the development of *A. fasciculatus* on all the dried chips used as well as reducing their life span. Addition of lime and fermented maize water retained the phytochemical present in all the treatments and facilitate the efficacy of the treatment by possessing pesticidal properties. These are similar to the findings of Adusei- Mensah et. al., (2014) who reported on insecticidal and repellent properties of *Citrus aurantifolia* against Carpenter ant (*Camponotus nearcticus).*

Phytochemical screening showed the important secondary metabolite such as alkaloids, phenols, saponin and tannin, which reduced the level of infestations of *A. fasciculatus* on stored chips. This is in line with the studies of Cowan (1999) and Rattan, (2010) who reported secondary metabolite of plant to serve as defense mechanism against predation by insects. Sensory evaluation conducted on all the treated dried chips revealed that there were no differences on all the parameter tested, that is, application of fermented maize water and lime did not have effect on the taste, colour, smoothness, elasticity, viscosity, odour, stickness and overall acceptance of cassava, potato, water yam, white yam and plantain.

CHAPTER SIX

6.1 Summary

The study on the survey of insects associated with cassava, potato, water yam, white yam and plantain showed two distinct insect order. The order coleoptera which consists of four primary pests namely, *Sitophilus zeamias* (maize weevil), *Araecerus fasciculatus* (Coffee bean weevil), *Dinoderus minutus*, *Rhyzopertha dominica* (Lesser grain borer), *Prostephanus truncatus* and two secondary pest, *Tribolium castaneum*, *Callosobruchus maculatus*. The order Hymenoptera were *Theocolax elegans* and *Cephalonomia waterstoni* which were present as dominant natural enemies. It was observed that insect was present in abundance on cassava, water yam and white yam across the locations because they offered the most suitable habitats and food supply for the sustenance and abundance of insects associated with them.

Araecerus fasciculatus oviposition started 6 to 7 days after emergence and last till 23rd days, they laid egg immediately after mating, incubation period of 3 to 7 days was discovered on all dried chips. Total larval developmental period was 19-29 days and pupa 2-4 days on all the dried chips used; there were four larval instar developmental stages and a total developmental period of F_1 was 40-55 days, 37-55 days, 35-60 days, 33-57 days and 36-52 days on cassava, potato, water yam, white yam and plantain respectively.

Plantain and cassava experienced highest percentage damage as well as highest amount of frass production due to preference, texture and their composition. Proximate and mineral analyses showed reduction of ash, crude fibre, dry matter, calcium, potassium, iron, phosphorus and increase in fat, crude protein and moisture content due to continuous feeding of insects on them.

When chips were blanched with fermented maize water and lime *A. fasciculatus* experienced prolonged developmental period and short adult longevity and low percentage damage. Addition of lime and fermented maize water retain the phytochemical present in all the treatments and facilitate the efficacy of the treatment by working as a pesticide. The treatment used allow the insect to oviposit and the eggs were able to hatch but prolong their development and adult longevity was very short due to reduced feeding on the food materials provided. Application of fermented maize water and lime did not have effect on the taste, colour, smoothness, elasticity, viscosity, odour, stickiness and overall acceptance of cassava, potato, water yam, white yam and plantain.

The residues mean concentrations in both dried cassava and dried yam chips were above the EU MRL for the food stuffs. The highest amount residue found in dried cassava and white yam chips was greater than EU's maximum residue limits, indicating that in all the samples analyzed, their percentage of OC residue were far above MRL.

6.2 Conclusion

The dominant insect across all dried chips were *Araecerus fasciculatus* and *Dinoderus minutus* which were found on all the dried chips: Cassava, potato, water yam, white Yam and Plantain. *Araecerus fasciculatus* was the most abundant specie present. *Araecerus fasciculatus* had seven life stages comprising of egg, four larval instars, prepupa/pupa and adult. There was variation in the developmental biology and description of *A fasciculatus* cultured on different dried chips. *Areaecerus. fasciculatus* caused significant damage to dried chips due to continuous feeding on them and also showed definite preference for different dried chips. *A. fasciculatus* experienced prolonged developmental period and short adult longevity and low percentage damage on chips blanched with fermented maize water and lime.

6.3 Contribution to Knowledge

The present study shows that:

i. Storage of different dried chips should be done separately to avoid cross infestation of storage pests

ii. The species diversity was high on cassava (H=2.01), water yam (H=1.88) and white yam (H=1.78) but low on potato (H=1.10) and plantain (H=1.35)
iii. The dominant insects across all dried chips are *Araecerus fasciculatus* and *Dinoderus minutus* which were found on all the dried chips, while the most abundance was *A. fasciculatus.*
iv. The developmental period of *Araecerus fasciculatus* was shorter on plantain (42 days) and longer on water yam (52 days)
v. Blanching of chips with a mixture of 740 mL fermented maize water, 250 mL water and 10 mL lime reduced infestation of *A. fasciculatus* in storage.

REFERENCES

A.O.A.C. 1984. 14th edition. Pg 187-188. INC IIII, North Nineteenth street, suite 210 Arlington VA 222-114

A.O.A.C. 1990. Official Methods of Analysis of the Association of Official Analytical Chemists. 15th Arlington, VA, 1234 pp.

Abdulahi, A. 2003. Employment Creation and Opportunities in the Agro-Allied Sub-Sector; the Case of Cassava Production. The Bullion Publication of CBN 27 (4): 1-10

Acuña, C. A., Martínez, E. J., and Quarin, C. L. 2004. Apospory followed by sterility in a hypotriploid hybrid of *Paspalum caryologia*, 57(4), 373-378.

Adesuyi, S. A. 1967. A survey of insect pests on dried yam and an investigation of the biology of the important species Rep. Nigeria in Stored Product Research Inst. Tech pp95-99.

Agona, J. A. 1995. Survey on storage pest complex of dried sweetpotato chips in Uganda, Paper presented at the sixth Triennial Symposium of International Society of Tropical Rots Crops- African Branch (ISTRC-AB), 22-28 October, Lilongwe, Malawi.

Ahmed, M., Akter, M. S. and Eun, J. B. 2010. Peeling, drying temperatures, and sulphite-treatment affect physicochemical properties and nutritional quality of sweet potato flour," Food Chemistry, vol. 121, no. 1, pp. 112–118.

Akoroda, M. O. and Nwokocha, H. N. 1996. Sweet potato in Nigeria, Production problems and prospects. Papers presented at the African Sweet potato seminar, Libraville, Gabon.

Alba-Alejandre, I., Alba-Tercedor, J., and Vega, F. E. 2018. Micro-CT to document the coffee bean weevil, *Araecerus fasciculatus* (Coleoptera: Anthribidae), inside field-collected coffee berries (Coffea canephora). Insects, 9(3), 100.

Alberto, J. 1958. A mandioca III Sues derivados, preparos e usos. Gaz. Agric. Angola, 3: 128-131.

Alimi, H, Mbarki, S, Ben Barka, Z., Feriani, A, Bouoni, Z, Hfaeidh, N, Sakly, M. Tebourbi, M, Ben Rhouma, K. 2013. Phytochemical, antioxidant and protective effect ofRhus

tripartitum root bark extract against ethanol-induced ulcer in rats, Gen.Physiol. Biophys. 32, 115 –127.

Alle, A., Dembelle, A., Yao, B. and Ado, G. 2009. Distribution of organochlorine pesticides in human breast milk and adipose tissue from two locations in Côte d'Ivoire. Asian Journal of Applied Sciences, 2(5), 456-463.

Alves, A. A. 2002. Cassava Botany and Physiology. In: Cassava: Biology, Production and Utilization. R.J. Hillocks, J.M. Thresh and A.C. Bellotti (eds).pp43.

Amandikwa, C., Iwe, M. O., Uzomah, A., Olawuni A. I. 2015. Physico-chemical properties of wheat-yam flour composite bread. Nigerian Food Journal, 33:12-17p.

Amoah, R. S., Sam-Amoah, L. K., Boahen C. A. and Duah, F. 2010. Estimation of the material losses and gari recovery rate during the processing of varieties and ages of cassava into gari. Asian J. Agric. Res., 4: 71-79.

Anonymous 1919. The preparation of "gaplek". Agric. Bull. Straits Fed. Malay States, 7: 370-371.

Anonymous 1941. Notes on preparation of "gaplek" from cassava (tapioca) roots. New Guinea Agric. Gaz., 7: 38.

Anzene, J. S., Tyohemba, R. L., Ahile, U. J., and Emezi, K. S. 2014. Organochlorine pesticide residues analysis of postharvest cereal grains in Nasarawa State, Nigeria. Int J Agron Agric Res, 5(5), 59-64.

Arbogast, R. T., Kendra, P. E., Mankin, R. W., and McDonald, R. C. (2002). Insect infestation of a botanicals warehouse in north-central Florida. Journal of Stored Products Research, 38(4), 349-363.

Archibald, R. D., Chalmers, J. 1983. Stored product Coleoptera in New Zealand. N.Z. Entomol. 7:371.397

Ardakani A. S. and Nasserzadeh, H. 2013. First record and biology of coffee bean weevil (Araecerus fasciculatus De Geer) on pesticide plant (Melia azedarach L.) from Iran. Journal of Medicinal and Aromatic Plant Sciences, 35(3/4):111-114.

Ardakani, A. S. and Nasserzadeh, H. 2014. First record and biology of Coffee Bean Weevil, *Araecerus fasciculatus* De Geer, on pesticide plant, Meliaazedarach L. from Iran. International Journal of Biosciences.4:486-491.

Asadu, P. O. 2004. “Presidential Initiative on Cassava Production and Export: Genesis and scope” Paper presented at a conference organized by National Cereal Research Institute held at Moor Plantation, Ibadan, Oyo State, Nigeria.

Asuming-Brempong, S., Gyasi, K. O., Marfo, K. A., Diagne, A., Wiredu, A. N., Asuming Boakye, A., Haleegoah, J., Frimpong, B. N. 1991. The exposure and adoption of New Rice for Africa (NERICAs) among Ghanaian rice farmers: What is the evidence? Afr. J. Agric. Res. 6(27):5911-5917.

Ayodele, B. C., Bolade, M. K. and Usman, M. A. 2013. Quality characteristics and acceptability of “amala” (yam-based thick paste) as influenced by particle size categorization of yam (Discorea rotundata) flour. Food Science Technology. International, 19(1), 35–43

Azalekor, W. 1999. Assessment of the Damage Caused by *Corcyra Cephalonica* (Stainton)(Lepidoptera: Pyralidae) and *Araecerus Fasciculatus* (Degeer)(Coleoptera: Anthribidae) to Stored Cocoa Beans in Ghana (Doctoral dissertation, University of Ghana).

Babajide, J. M., Bello, O. Q., Babajide S. O. 2010., Quantitative determination of active substances (preservatives) in *Pilostigma thonningii* and *Khaya ivorensis* leaves and subsequent transfer in the dry yam, African Journal of Food Science 4(6), 382-388

Babarinde, S. A., Kehinde, A., Kemabonta I. A., Aderanti, F. C., Kolawole, 1. and Adetayo D. A. 2018. Synergistic Effect of Spinosad with Selected Botanical Powders as Biorational Insecticides Against Adults of *Tribolium Castaneum* Herbst, 1797 (COLEOPTERA: TENEBRIONIDAE) Journal of Agricultural Sciences Vol. 63, No. 1, Pages 39-51

Bamire, A. S. and Amujoyegbe, B. J. 2005. Economic analysis of Land improvement techniques in small-holder Yam-Based Production systems in the agro-Ecological Zones of South Western, Nigeria. Journal of Human Ecology. 18(1): 1-12.

Beevi, S. R.., Visalakshi, A. and Mammen, K. V. 1991. Nature and extent of damage caused by insect pests to stored cassava chips. In Recent advances in the production and utilization of tropical tuber crops, Eds., Nair, N.G., M.S. J. Root Crops, 17: 197-200.

Bempah, C. K., and Donkor, A. K. 2011. Pesticide residues in fruits at the market level in Accra Metropolis, Ghana, a preliminary study. Environmental monitoring and assessment, 175(1), 551-561.

Best, E. 1925. Maori Agriculture. Bull. No. 9. New Zealand, Dominion Mus.

Bitran, E. A., Campos, T. B. and Oliveira, D. A. 1978. Aspects of the development of infestations of *Araecerus fasciculatus* De Geer (Col; Anthribidae) in different food substrates. Arquivo do Instituto Biologico 45 (4) 281-286.

Bjeldanes, L .and Shibamoto, T. 2009. Introduction to Food Toxicology (2nd ed.). Burlington: Elsevier. p. 124. ISBN 9780080921532.

Blagbrough, I. S., Bayoumi, S. A. L., Rowan, M. G. and. Beeching, J. R. 2010. "Cassava: an appraisal of its phyto chemistry and its biotechnological prospects—review, "Phytochemistry, vol.71, no.17-18,pp.1940–1951

Bohm, B. A., Koupai-Abyazani, M. R. 1994. Flavonoid and condensed tannins from Leaves of Hawaiian Vaccininum vaticulumand V. calycinum Ericaceae. Pacific Science 48(4): 458-463.

Boxall, R. A. 1986. A Critical Review of the Methodology for Assessing Farm-level Grain Losses after Harvest. Slough, U.K.: Tropical Development and Research Institute.

Breslin Andrew. 2017. "The Chemical Composition of Green Plants". Sciencing, Leaf Group Ltd.

Bricas, N., Vernier, P., Ategbo, E., Hounhouigan, J. D., Mitchikpe, E., N'kpenu. K. E., Orkwor, G. 1997. Le development la filiere cossettes d'igname en Afrique de l'Quest. Cashiers de la recherché Development. 44(2): 100-114.

Brunner, J. H 1984. Direct Spectrophotometer determination of Saponin. Anal. Chem. 34, pg 1314 - 1326.

Caasi-Lit, M. T., and Lit Jr, I. L. 2011. First report of the coffee bean weevil Araecerus fasciculatus (De Geer)(Coleoptera: Anthribidae) as pest of papaya in the Philippines. Philippine Agricultural Scientist, 94(4), 415-420.

Cabal Concha, A. 1952. Biología y control del gorgojo del café: Araecerus fasciculatus De Geer Fam: (Anthribiidae), en Barranquilla—Colombia. Rev. Facul. Nacional Agron. 18, 49–72.

CABI International. 2005. Crop Protection Compedium, Global module, 2nd Edition Wallingford, UK. CAB International.

Chacko, M. J. and Bhat, P. K. 1979. Preliminary studies on control of A. fasciculatus inflicting coffee by bag impregnation. Journsl of coffee Research 9(1), 24-25.

Chandrasekara, A., and Josheph Kumar, T. (2016). Roots and tuber crops as functional foods: a review on phytochemical constituents and their potential health benefits. International journal of food science, 2016.

Chemkhi, S., Zagrouba, F., and Bellagi, A. (2005). Modelling and simulation of drying phenomena with rheological behaviour. Brazilian Journal of Chemical Engineering, 22(2), 153-163.

Chijindu, E. N. and Boateng, B. A. 2008. Preference of and damage to processed cassava chips by *Araecerus fasciculatus* (De geer). Journal of Applied Sciences Research, 4(8), 939-944.

Childers, C. C. and Nigg. H. N. 1982. Contact toxicity of insecticides to adults of the coffee bean weevil (Col; Anthribidae). Journal of Economic Entomology. 75 (3) 556-559.

Childers, C. C., and Woodruff, R. E. 1980. A Bibliography of the Coffee Bean Weevil *Araecerus fasciculatus* (Coleoptera: Anthribidae). Bulletin of the ESA 26 (11): 384-394.

Chittaranjan, K. (2007). Genome Mapping and Molecular Breeding in Plants. Vol. 3: Pulses, Sugar and Tuber Crops.

Clemente, L. S. 1918. A study of *Dioscorea* with starch determination and cooking tests. Philipp. Agric. Forest, 6 (8): 230-246.

Compton, J. A. F., Floydb, S., Ofosua, A. and Agboa, B. 1998. The modified count and weigh method: an improved procedure for assessing weight loss in stored maize cobs Journal of Stored Products Research 34 (4):277-285.

Cornelius, E. W. and Oduro, K. A. 1999. Storage diseases of white yam (*Dioscorea rotundata* Poir): Causes, varietal susceptibility and control. J. Ghana Sci. Assoc., 1: 45-52.

Cotterell, G. S. (1952). The insects associated with export produce in Southern Nigeria. Bull. ent. Res. 43 (1), 145-152.

Cotton, R. T. 1921. Four Rhynchophora attacking corn on storage. J. Agric. Res. 20 (8), 605-614.

Cowan, M. M. 1999. Plant products as antimicrobial agents. Clin. Microbiol. Rev., 12: 564-582.

Craufurd, P. Q., Summerfield, R. J., Asiedu, R. and Vara Prasad, P. V. 2001. Dormancy in yams. Experimental Agriculture 37(2): 147-181 [7506]

Danjuma, S. 2002. Studies on Damage by *Prostephanus Truncatus (*Horn)(Coleoptera*:* Bostrichidae) And *Araecerus Fasciculatus* (Degeer)(Coleoptera: Anthribidae) to Dried Yam Chips (Doctoral dissertation, University of Ghana).

Darko, G., Akoto, O. and Oppong, C. 2008. Persistent Organochlorine Pesticide Residues in Fish, Sediments and Water from Lake Bosomtwi, Ghana. *Chemosphere*, **72**, 21-24. http://dx.doi.org/10.1016/j.chemosphere.2008.02.052

Decary, R. 1946. Plantes et animaux utiles de Madagascar. Ann. Mus. Colon., Marseille, 4 (6 ser.): 1-222.

DeGeer, G. 1775. Momoire pour servir a 1'histoire des insects. 17(7), 276pp Stockholm

Dominguez, P. L. (1992). Feeding of sweet potato to monogastrics. Roots, tubers, plantains and bananas in animal feeding (Editors: D Machin and S Nyvald) FAO: Rome, 217-233.

Du, G., He, S., Song, X., Liao, Q. I., Zhang, X. and Yue, B. 2016. The complete mitochondrial genome of *Epicauta Chinensis* (Coleoptera: Meloidae) and Phylogenetic analysis among Coleopterans insects. Gene 578. 2: 274-280

Duke, J. A. (1983). Handbook of energy crops. Handbook of Energy Crops.

Eagleston, G. B., Okoye M. B. and Jeon V. M. 1992. Traditional African Methods of Cassava Processing and Utilisation and Research Needs. In Tropical Root Crops Production of Roots Crops-Based Industries. Pp.4-6

Ecocrop, 2010. Ecocrop database. FAO

Eke-Okoro, O. N., Njoku, D. N., Mbe, J. O., Awah, J. I., Amanze, N. J. and Eke-Okoro, O. C. 2014. Contribution of root and tuber crops in the Agricultural transformation agenda in Nigeria. J. Agric. Biol. Sci., 9, 1990–6145.

Essumang, D. K., Asare, E. A., & Dodoo, D. K. 2013. Pesticides residues in okra (non-target crop) grown close to a watermelon farm in Ghana. Environmental monitoring and assessment, 185(9), 7617-7625.

Eze, N. O. A. 1998. Economics of Technology. *In*: Food Yams: Advances in research. G. C Orkwor, R. A. Asiedu and I.J. kanayake, eds. NRCRI/IITA, Ibadan, Nigeria. Pp 187-214

FAO (Food and Agriculture Organization) 2007. F.A. FAO STAT. Statistics Division of Food and Agriculture Organization …www. Faostat.org. accessed July 21, 2010.

FAO, 1988. FAO Year Book production. Vo1. 42; Food and Agricultural organization of the United Nations, Rome Italia, 1988.

FAO. 2017. FAO Briefing Note on FAW; The Food and Agriculture Organization of the United Nations: Rome, Italy,; p. 5. 6.

FAO. 2008. Food outlook Food and Agricultural Organization Corporate Document Repository. http://www.fao.org/docrep/012/ak341e/ak341e06.htm.

FAO. 2010. FAOSTAT database. Food and Agriculture Organization, Roma, Italy. Available online at URL: www.fao.org.

FAO/IFAD. 2001. The Global Cassava Development Strategy and Implementation Plan. Proceedings of the Validation Forum on the Global Cassava Development Strategy

FAOSTAT. 2009. Online Statistical Database. Rome, Italy.www.fao.org.

Ferraro, V., Piccirillo, C., Tomlins, K., and Pintado, M. E. 2016. Cassava (Manihot esculenta Crantz) and yam (*Dioscorea spp*.) crops and their derived foodstuffs: safety, security and nutritional value. Critical reviews in food science and nutrition, 56(16), 2714-2727.

Figuereido Jr, E. R. (1957). O contrôle do "caruncho" das tulhas. *O Biol*, *23*, 197-200.

Friederichs, K. (1925). Beobachtungen an simuliiden in Ost-Java. Archiv fur Schiffs-und Tropenhygiene, 29, 119-129.

Gater, B. A. R. (1925). Some Observations on the Malaysian Coconut Zygaenid (Artona catoxantha, Hamps.). Malayan Agricultural Journal, 13(4).

Girardin, O. 1996. Postharvest Technology of the Yam: A Study of Improved Traditional Storage in Côte d'Ivoire. Ph.D. Thesis, Ecole Polytechnique Fédérale de Zurich, Zürich, Switzerland,

Goncalves, L. I., Bitran, H. V., and Bitran, E.A. 1976. Contribution to the study of the biology of the coffee borer *Araecerus fasciculatus* (Col: Anthribidae) Biologico 43(3/4), 81-88.

Grout, T. G., Begemann, G. J., and Stephen, P. R. 2001. Monitoring and control of coffee bean weevil, Araecerus coffeae (Coleoptera: Anthribidae), in southern African citrus orchards. African Plant Protection, 7(2), 67-72.

Gruēle, A. G. and Smale, M. 2006 "Marketing underutilized plant species for the benefit of the poor. A conceptual framework," Paper 154, Environment and Production Division.

Hahn, N. D and Onabolu, A. 1988. Potential of sweet (low cyanide) cassava as a household food security crop. pp 119-124 in Contributions from the second Annual meeting of the collaborative group in cassava - based cropping systems research, Ibadan. 7-10 Nov. 1988, IITA, Ibadan, Nigeria.

Haines, C. P. (1991). Insects and arachnids of tropical stored products: Their biology and identification (No. 632.7 N2194i Ej. 1 006993). NRI,

Halliwell, B 2007. "Dietary polyphenols: Good, bad, or indifferent for your health?" CardiovascularResearch. 73 (2):3417. doi:10.1016/j.cardiores.2006.10.004. PMID 17141749.

Halstead, G.H. 1963. External Sex differences in stored products Coleoptera. Bulletin of Entomological Research, 54:119-134. Hahns, S.K. and J. Keyser, 1985. Cassava: A basic food in Africa. Outlook Agric., 4: 95-100.

Handy, E.S.C. 1940. The Hawaiian Planter: His Plants, Methods and Areas of Cultivation. Bull. 161. Bernice P. Bishop Museum, Honolulu.

Harborne, Jeffrey B.; Baxter, Herbert; Moss, Gerard P., eds. 1999. "General Introduction". Phytochemical dictionary a handbook of bioactive compounds from plants (2nd ed.). London: Taylor & Francis. *p. vii.* ISBN 9780203483756.

Henry T. A 1993. – a textbook titled The plant Alkaloids pg 6-466 Allen's commercial organic Analysis, 1992, Vol. Vi pp 167 – 168

Hill, D. S. 1990. Pests of stored products and their control. Belhaven press, London WC2E 9DS. 540pp.

Hiranandani, G. J. and Advani, K. H. 1955. Report on the marketing of tapioca in India. Mark. Ser. No. 88. Directorate Mark. Inspect., Minist. Food Agric., India.

Hoy, M. A., 2003. Insect molecular genetics. Academic Press, San Diego CA, USA, 2nd Edition, 544 p.

Idumah, F. O. Owombo, P. T. and Ighodaro U. B. 2014. Economics of Yam Production under Agroforestry System in Sapoba Forest Area, Edo State, Nigeria, International Journal of Agriculture and Forestry, 4(6): 440-445

Iheagwam, E. U. 1986. Preliminary observations on the entomofauna of the water yam Dioscorea alata L. during storage. D. tsch.ent., N.F. 33(1-2), 7173

IITA 1987. Root and tuber Improvement programme pp. 89-105.

IITA, 1999. Cassava Catches on International Institute of Tropical Agriculture Annual Report. IITA, Ibadan, Nigeria, pp: 27.

IITA. 2007. International Institute of Tropical Agriculture. Nigeria. Annual Report 2007. p. 99.

Iqbal, J. 2017. Coleoptera, insects, mites & earthworms, *Araecerus fasciculatus*: Coffee Bean Weevil, Pest Rating Proposal

Isah, M. D., Ayertey, J. N. and Boateng, B. A. 2009. Suitability of dried chips of plantain, Cocoyam, yam and cassava for the development of the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Int. J. Pure Applied Sci., 3: 12-20.

Iwasaki, S. 1998. "Natural organic compounds that affect to microtubule functions". Yakugaku Zasshi. 118 (4): 112–26. PMID 9564789.

Iwueke, C. C., Mbata, E. N. and Okereke, H. E. 2003. Rapid Multiplication of seed yam by minisett technique. National Root Crops Research Institute, Umudike, Abia State, Nigeria, Advisory Bulletin 2003 No 9 pp5

Iyagba, A. G. 2010. A review on root and tuber crop production and their weed management among small scale farmers in Nigeria. Journal of Agricultural and Biological Science. 5(4): 52-58.

Izeko O. B and Olumeze M. I. 2010. Determinant of yam production and profitability in Edo state, Nigeria. Afr. J. General Agric., 6(4), 62-69.

Lebot, V., Champagne, A., Malapa, R., & Shiley, D. (2009). NIR determination of major constituents in tropical root and tuber crop flours. Journal of Agricultural and Food Chemistry, 57(22), 10539-10547.

Jakubczyk T. E. 1982. Roots and Tubers Processing in Some African Countries. In: African Regional Centre for Technology (ARCT) (ed.) Roots and Tubers Production, Storage, Processing and Marketing in Africa, Dakar, pp. 112-126.

Janick, J. 1981. Plant science: an introduction to world crops (3rd ed). W.H. Freeman and Co., San Francisco, CA, USA.

Jonathan, G., Ajayi, I. and Omitade, Y. 2011. Nutritional compositions, fungi and aflatoxins detection in stored gbodo (fermented *Dioscorea rotundata*) and elubo ogede (fermented

Musa parasidiaca) from South western Nigeria. African Journal of Food Science 5(2), 105–110.

Jones W. O. 1959. Manioc in Africa. Standard University press, Stanford, Calif., U.S.A p. 3-36

Jones, J. D. and Dangl, J. L. 2006. The plant immune system. Nature 444, 323-329. 4.

Jones, W. O. 1959. Manioc in Africa. Stanford Univ. Press, Stanford, California, U.S.A.

Joslyn, M. A. (1970). Tannins NAD related phenolics. In: Methods in food analysis, 701- 725. Journal of Cell Biochemistry, 22, 188–9

Kanamugire, J. and Afadhali, J. P. 2017. Rwanda faces hunger over fall army worm invasion. In The East African; Nation Media Group: Kigali, Rwanda.

Kerr, A. J. 1941. Cassava. E. African Agric. J., 7: 75-76.

Kohno M., Mochizuki K., Chuman T., Ohnishi A. 1986. Pheromone-like substances affecting the oviposition behavior of the female cigarette, *Lasioderma serricorne* (F.) (Coleoptera: Anobidae). Applied Entomology and Zoology. 21, 15-20

Kolani, L., Sanda, K., Agboka, K., Mawussi, G., Koba, K., and Djouaka, R. 2016. Investigation of insecticidal activity of blend of essential oil of Cymbopogon schoenanthus and neem oil on *Plutella xylostella* (Lepidoptera: Plutellidae). Journal of Essential Oil Bearing Plants, 19(6), 1478-1486.

Korada, R. R., Naskar, S. and Edison, S. 2010. Insect pests and their management in yam production and storage: a world review.

Kormawa, P. and Akoroda M. O. 2003. Cassava Supply Chain Arrangement for Industrial Utilization in Nigeria. Ibadan.

Kossou, D. K. and Bosque-Perez, N. A. 1998. Insect Pests of maize in Storage: Biology and Control. IITA Research Guide 32. Training Programme. International Institute of Tropical Agriculture (IITA), Nigeria. Third Edition, 28pp.

Kumar, G.A. and Karnavar, G.K. 1986. Reproductive biology of the stored product pest -**A.** fasciculatus (Co1: Anthribidae) Entomon., I1 (4), 309-310.

Lin T**.** 1976. Studies on life cycle and control of coffee bean weevil, *Araecerus fasciculatus* (De Geer) (Coleoptera: Anthribidae). Journal of Agricultural Research of China **25,** 44-52.

Lindsay, W. P., Lamb, C. J. and Dixon, R. A. 1993. Microbial recognition and activation of plant defense systems. Trends Microbiol., 1, 181-187.

Liu, Y. W., Shang, H. F., Wang, C. K., Hsu, F. L. and Hou, W. C. 2007. Immunomodulatory activity of dioscorin the storage protein of yam (*Dioscorea alata* cv. Tainong No. 1) tuber, Food and Chemical Toxicology, vol.45, no.11, pp. 2312–2318

Longino, J. 1994. How to measure arthropos diversity in a tropical rainforest. Biol. Int. 28: 3-13.

Madziga, H. A., Sanni, S., & Sandabe, U. K. 2010. Phytochemical and elemental analysis of Acalypha wilkesiana leaf. Journal of American Science, 6(11), 510-514.

Magurran, A. E. 2004. Measuring Biological Diversity. 2nd edition. Oxford: Blackwell Publishing.

Markham, R. H. 1981. The ecology of insect pest populations in maize storage cribs in Nigeria.

McDonald L. L., Guy R. H. and Speirs R. D. 1970. Preliminary evaluation of new candidate materials as toxicants, repellents and attractants against stored product insects —I. Marketing Research Report No. 882. Agricultural Research Service, US Department of Agriculture, Washington DC. 8 pp.

Mestres C., Dorthe S., Akissoe N. and Hounhouigan J. D. 2004. Prediction of sensorial properties (colour and taste) of Amala, a paste from yam chips flour of West Africa, through biochemical properties. Plant Foods Hum. Nutr. 9 (3): 93-99.

Methods of Analysis of Analytical Methods Committee of Royal Society of Chemistry.AMC-RSC.pp222-239.

Michael (1998). Alkaloids : biochemistry, ecology, and medicinal applications. New York: Plenum Press. p. 20. ISBN 978-0-306-45465-3.

Molyneux, R. J, Lee, S. T, Gardner, D. R, Panter, K. E, James, L. F. 2007. "Phytochemicals: the good, the bad and the ugly?" Phytochemistry. 68 (22–24): 2973–85. doi:10.1016/j.phytochem.2007.09.004. PMID 17950388.

Mphuru, A. N. 1974. Araecerus fasciculatus DeGeer (Col : Anthribidae), A review. Tropica1 stored products information

Nagano, M. 1981. Coffee bean weevil injurious to garlic. Proceedings of the Assoc. for plant protection of Kyushu 25:92-94.

Nassar, N. M. A., Hashimoto, D. Y. C. and Fernandes, S. D. C. 2008. “Wild Manihot species: botanical aspects, geographic distribution and economic value,” Genetics and Molecular Research, vol. 7,no.1, pp.16–28

Nigam, P. S., Gupta, N., and Anthwal, A. (2009). Pre-treatment of agro-industrial residues. In Biotechnology for agro-industrial residues utilisation (pp. 13-33). Springer, Dordrecht.

Nukenine, E. N. "Stored product protection in Africa: Past, present and future." *Julius-Kühn-Archiv* 425 (2010): 26.

Nwana, I. E. and Azodeh, I. C. 1984. Tho effect of variety and method of processing 3n dried yam damage by *Araecerus fasciculatus*. De geer (Co1:Anthribidae). Tropical stored products information 49:3-7.

Nweke, F. I. 2004. Cassava: A cash crop in Africa. A Collaborative Study of Cassava in Africa, working paper. No. 14.

Odeyemi, O. O. and Daramola, A. M. 2000. Storage practices in the tropics. Volume 1. Food storage and pest problem (1st Ed) Dave Collins Publication, Nigeria, 253 Pp

Ogunfowokan, A. O., Oyekunle, J. A. O., Torto, N. and Akanni, M. S. 2012. A study on persistent organochlorine pesticide residues in fish tissues and water from an agricultural fish pond. Journal of Food Agriculture 24 (2), 165-184.

Ojo, J. A., and Omoloye, A. A. 2016. Development and life history of *Sitophilus zeamais* (Coleoptera: Curculionidae) on cereal crops. Advances in Agriculture, *2016*.

Oke, O. A and Odebiyi, J. A. 2008. Rearing procedure for the pre-imaginal stages of the flea beetle (*Podagrica sjostedti*) (Coleoptera: Chrysomelidae), and its developmental biology on okra (*Abelmoschus esculentus*). International Journal of Tropical Insect Science 28 (03): 151-157.

Oke, O. L. 1965. Chemical studies on some Nigerian foodstuffs "lafun". W. African Biol. Appl. Chem., 8: 53-56.

Okonya, J. S. and Kroschel, J. A. 2015. Cross-sectional study of pesticide use and knowledge of smallholder potato farmers in Uganda. Biomed. Res. Int.

Okonya, J. S., Ocimati, W., Nduwayezu, A., Kantungeko, D., Niko, N., Blomme, G., ... & Kroschel, J. (2019). Farmer reported pest and disease impacts on root, tuber, and banana crops and livelihoods in Rwanda and Burundi. *Sustainability*, *11*(6), 1592.

Oliveira, M. M., Tribst, A. A. L., Júnior, B. R. D. C. L., de Oliveira, R. A., & Cristianini, M. (2015). Effects of high pressure processing on cocoyam, Peruvian carrot, and sweet

potato: Changes in microstructure, physical characteristics, starch, and drying rate. Innovative food science & emerging technologies, 31, 45-53.

Olufade, Y. A., Sosan, M. B. and Oyekunle, J. A. O. 2014. Levels of Organochlorine insecticide residues in cowpea grains and dried yam chips from markets in Ile-Ife, Southwestern Nigeria: A Preliminary Survey. Ife Journal of Science, 16(2): 161-170.

Omohimi, C., Piccirillo, C., Roriz, M., Ferraro, V., Vasconcelos, W. M., Sanni, L. O., Pintado, M. M. and Abayomi, L. A. 2017. Study of the proximate and mineral composition of different Nigerian yam chips, flakes and flours. Journal of Food Science Technology. 55, 42–51

Omojola, J. T. 2014. Gross margin analysis and constraints to yam production in Osun State, Nigeria, World Journal of Agricultural Sciences Vol. 2 (4), pp. 062-068,

Opara, L. U. 1999. Yam storage In: Bakker- Arekema et.al., (eds). CIGR Handbook of Agricultural Engineering. Vol. IV. Agro Processing. 1999: 182-214.

Osbourn, A. E. 2003. Saponins in cereals. Phytochemistry, 62, 1-4.

Osei, M. K., Taah, K. J., Berchie J. N. and Osei, C. K. 2009. A survey of cassava (Manihot esculenta Crantz) planting materials in storage: A case study in two communities in the ejisu district of ashanti region, Ghana. J. Agron., 8: 137-140.

Osuji, F.N.C. 1980. Observations on beetle attacking dried yams and yam flour from three Nigerian markets. Tropical stored products information 39:35-38.

Osunde, Z. D. 2008. Minimizing Postharvest Losses in Yam (Dioscorea spp.): Treatments and Techniques. In Using Food Science and Technology to Improve Nutrition and Promote National Development; Robertson, G.R., Lupien, J.R., Eds.; International Union of Food Science and Technology: Toronto, ON, Canada,

Oxford Dictionary of Biochemistry and Molecular Biology. Oxford University Press, 2006. ISBN 0-19-852917-1.

Oyo-Ita, O. E., Ekpo, B. O., Adie, P. A. and Offem J. O. (2014). Organochlorine pesticides in sediment dwelling animals from mangrove areas of the Calabar River, SE Nigeria. Environment and Pollution, 3:3

Palaniswami, M. S and Peter K. V., 2008. Tuber and Root crops: Vol, 09: Hort. Sci. Series. New Indian publishing. Pgs 4-10; 211-214.

Papadopoulou S.C. 2006. Observations of the mating behaviour of *Lasioderma serricorne* (F.) adults and experiments on their nutritional requirements in dried tobacco. The Coleopterists Bulletin. 60(4): 291-296.

Parker, B.L., Booth, R.H. and Haines, C.P. 1981. Arthropods infesting stored cassava (Manihot esculenta Crantz.) in peninsular Malaysia. Protection Ecology, 3: 141-156.

Paulino, L.A., Yeung, R 1981. The food situation in sub-Saharan Africa: a preliminary assessment. In IFPRI food policy issues and concerns in sub-Saharan Africa. International Food Policy Research Institute, Washington, DC, USA.

Patterson, W. H. (1928). Insect attacks on cured cocoa. *Trop. Life*, *281*, 35-36.

Pedersen, I. R. 1979. Selection of Oviposition sites on wheat grains by *Sithophilus spp.* Effect of moisture, temperature and grain size PhD. Dissertation, Kansas State University, Manhattan, Kansas. 204pp

Pillai, K. S and Rajamma P. 1997. Post Harvest Insect Pest Management of Tropical Tuber Crops, Technical Bulletin Series: 20. Thiruvananthapuram, Kerala, India: Central Tuber Crops Research Institute. p. 27.

Pillai, K. S. 1977. Proc. Fourth Symp. Intl. Soc. Trop. Root Crops, Cali, CIAT, Ottawa, IDRC, Potential New Pest of Citrus in Florida. Entomology Circular. No. 117.

Puzzi, D. and Orlando, A. 1963. Studies on fumigant dosages for the control of *A. fasciculatus* under a plastic envelop. Biologico, 29 (7), 127-130.

Quereshi, A. H. 1966. The toxicity of hydrogen phosphide to some insect pests of stored products fumigated in 44-gallon drums containing cocoa. Rep. Nigerian stored Prod. Res. Inst. 1966, 133-136.

Rajamma, D., Padmaja G. and Lakshmi, K. R.. 1994. Residual Cyanide in Processed Cassava Chips Related to Storage Insects. Central Tuber Crops Research Institute (CTCRI), Trivandrum, India, pp: 451-452.

Rajamma, P., Premkumar, T., Kurup G. T., Palaniswami, M. S., Potty, V. P., Padmaja. G, Kabeerathumma, S., Pillai, S. V. 1996. Influence of varieties and method of processing on insect infestation in dry cassava chips. Tropical Tuber Crops: Problem, Prospects and Future Strategies, pp. 321-328.

Rattan, R. S. 2010. Mechanism of action of insecticidal secondary metabolites of plant origin. Crop Protection, 29 (9), 913-920.

Rees, D. A. V. I. D. (2007). Insects of stored grain. *Australia, Collingwood VIC*, *3066*.

Robert, E., Woodruff, A. S. 1972. The Coffee Bean Weevil, Araecrerus fasciculatus (DeGeer): A Ronald Cohen (Ed). 5(9): 213-215

Samways M. J., Bazelet C. S., and Pryke J. S. 2010. Provision of ecosystem services by large-scale corridors and ecological networks. Biodivers Conserv (this issue)

Sanginga, N. 2015. Root and Tuber Crops (Cassava, Yam, Potato and Sweet Potato) Background Paper-Feeding Africa: Action Plan for African Agricultural Transformation, 21-23

Sanni, S. A., Oguntona, C. R. B. and Bamgbose, A. M. 2009. Iron bioavailability and utilization in rats fed cassava fufu flour diet fortified with different sources of iron. Journal of Food Agriculture and Environment 7, 131–135.

Sayed, M. T. EL. 1935, on the biology of *araecerus fasciculatus* de geer (col., anthribidae), with special refference to the effects of variations in and water content of the food. Annals of applied biology, 22: 557–577. Doi: 10.1111/j.1744-7348.1935.tb07152.x

Sayed, M.T. EL. 1940. The morphology, anatomy and biology of A. fasciculatus DeG. Bull. Society fouad le Ent. 24, 82-150.

Scott, G. J. Rosegrant, M. W., Ringler, C. 2000. Global projections for root and tuber crops to the year 2020. Food Policy, 25, 561–597

Sefa-Dedeh S. and Kofi-Agyir S. E. 2002. Starch structure and some properties of cocoyam (*Xanthosoma sagittifolium* and *Colocasia esculenta*) starch and raphides. Food Chemistry 79: 435-444(10).

Sefa-Dedeh, S. and Agyir-Sackey, E. K. 2004. Chemical composition and the effect of processing on oxalate content of cocoyam *Xanthosoma sagittifolium* and *Colocasia esculenta* cormels. Food Chemistry 85: 479–487.

Shaw, D. 2010. "Toxicological risks of Chinese herbs". Planta Medica. 76 (17): 2012–8. doi:10.1055/s-0030-1250533. PMID 21077025.

Sneath, P.H.A. and R.R. Sokal., 1973. Numerical taxonomy: the principles and practice of numerical classification. San Francisco, CA:W.H.Freeman.

Sosan, M. B., Oyekunle, J. A. O. and Olufade, Y. A. 2015. Dichlorodiphenyltrichloroethane (DDT) and Hexachlorohexane (HCH) Pesticide Residues in Foodstuffs from Markets in Ile-Ife, Nigeria. International Journal of Biological and Chemical Sciences, 9(1): 442-453

Stumpf, E. 1998. Post-Harvest Loss due to Pests in Dried Cassava Chips and Comparative Methods for its Assessment: A Case Study on Small Scale Farm House Holds in Ghana. Berlin, Germany, Pages: 172.

Subrahmanyam, V. 1963. Monsooned coffee, Indian Coffee, 27-11-15.

Tsegai, D. and. Kormawa P.C (2002). Determinants of Urban Household Demand for Cassava Products in Kaduna, Northern Nigeria. In: Conference of International Research for Development, Witzenhaus.

United States Department of Agriculture **(USDA).** 1971 Notes on -A. fasciculatus affecting citrus. Notes from the scientific Records systems to Dec. 1971. Aphis aphis, plt. Prot. Quar. Prog. Hyatsville, MD, lp.

USDA. 2012. USDA Guide to Stored Pests." USDA – Grain Inspection, Packers & Stockyards Administration. USDA,.

Usman, S. 1949. The coffee berry borer. -A. f ascizulatus (Deg). Mon. Bul1 Indian coffee Bd. 13(10), 142-149.

Valentine, B. D. (2005). The scientific name of the coffee bean weevil and some additional bibliography (Coleoptera: Anthribidae: Araecerus Schönherr). *Insecta Mundi*, 98.

Walker, K. 2007. Coffee bean weevil (Araecerus fasciculatus) Updated on 1/25/2008 Available

Wall, M.E., Eddy, C. R., McClenna, M. L. and Klump M. E. 1952: Detection and estimation of Steroid and Sapogenins in plant tissue. Analytical Chemistry,24:1337-1342

Waller, J. M., Bigger, M., & Hillocks, R. J. (2007). Coffee pests, diseases and their management. CABI.

Wang, X., Ren, N., Qi, H., Ma, W. and Li, Y. 2009. Levels, distributions, and source identification of organochlorine pesticides in the topsoils in Northeastern China. Journal of Environmental Sciences, 21: 1386-1392.

Waong, A., Ba, N. D., Dabire-Binso, L.C. and Sanon, A. 2015. Diversity and community structure of Insects pests developing in stored sorghum in the Northern-sudan ecological zone of Burkina Faso. Journal of Stored Products Research 63: 6-14

Westby, A. 2002. Cassava utilization, storage and small-scale processing. In: Hillocks RJ, Thresh JM, Belloti AC (eds.) Cassava: biology, production and utilization. CAB International Publishing, Wallingford. pp. 281-300

Widstrom. N. W., Redlinger. L. M. and Wiser. W. J. 1972. Appraisal of methods for measuring corn kernel resistance to *Sitophilus zeamais*. Ann. Entomol. Soc. Am. 65(3): 790-792.

Woodruff, R. E. 1972. The coffee bean weevil, *Araecerus fasciculatus* De Geer. A potential new pest of citrus in Florida (Co1:Anthribidae) Fla. Dept. Agric. Consum. Serv. Div. Plt Ind. Entomol. Circ. No. 117,2pp.

Woolfe, J. A, 1992. Sweet Potato: An Untapped Food Resource, Cambridge University Press, Cambridge.

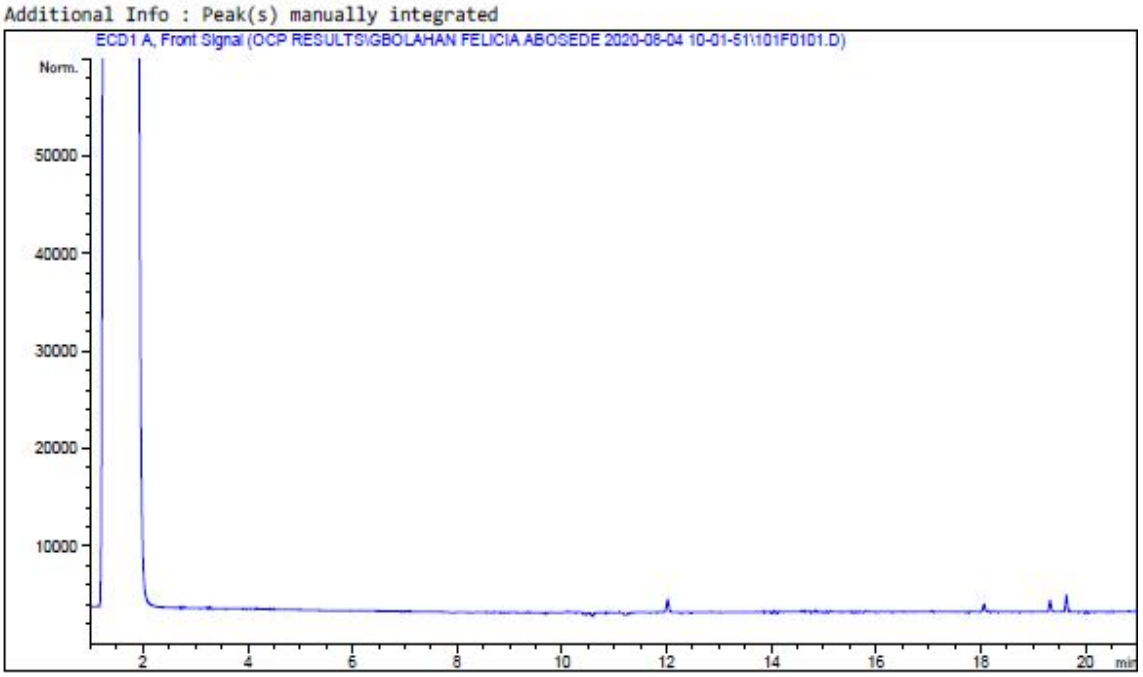
Wrigley, G. (1988). *Coffee* (p. 369). Essex: Longman Scientific & Technical.

Wu, Y., Chen, B. and GuoTeng, O. 2011. Damage of coffee bean weevil (*Araecerus fasciculatus* De Geer) on its new host *Jatropha curcas* L.The Journal Board of Plant Diseases and Pests, Cranston, USA, Plant Diseases and Pests 2 (2): 22-24.

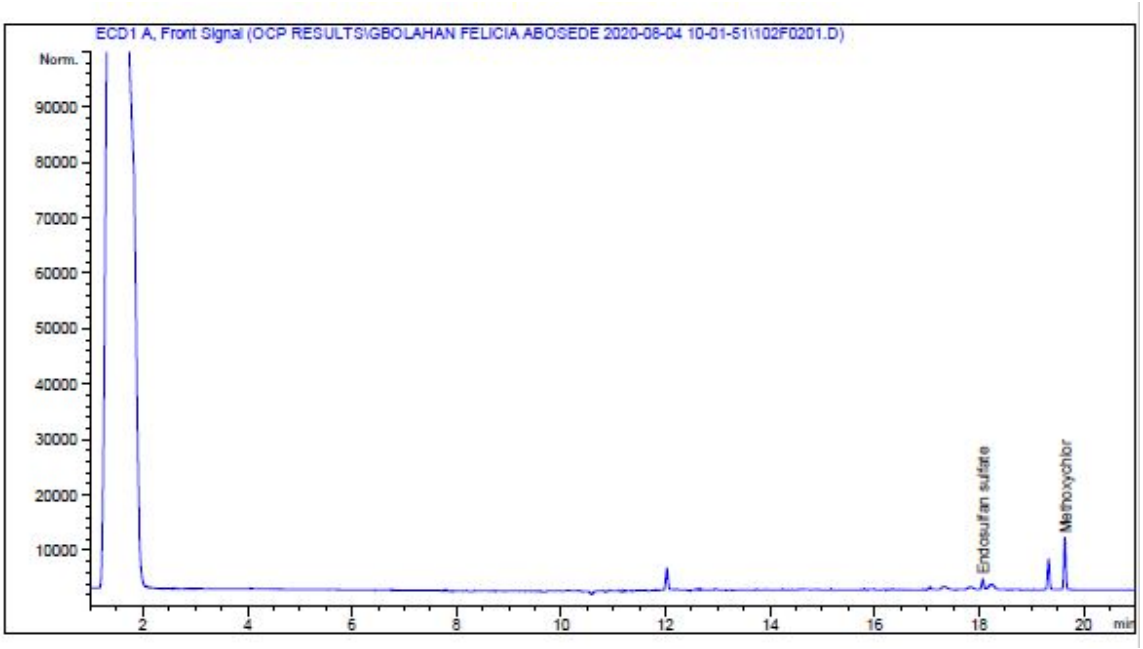
Yen, D. E. 1974. The sweet potato and Oceania. Bull. 236. Bernice P. Bishop Museum, Bishop Museum Press, Honolulu.

Zeller, F. J. 2005. Origin, diversity and breeding of banana and plantain (Musa spp.). Journal of Agriculture and Rural Development in the Tropics and Subtropics, Supplement. 1-42.

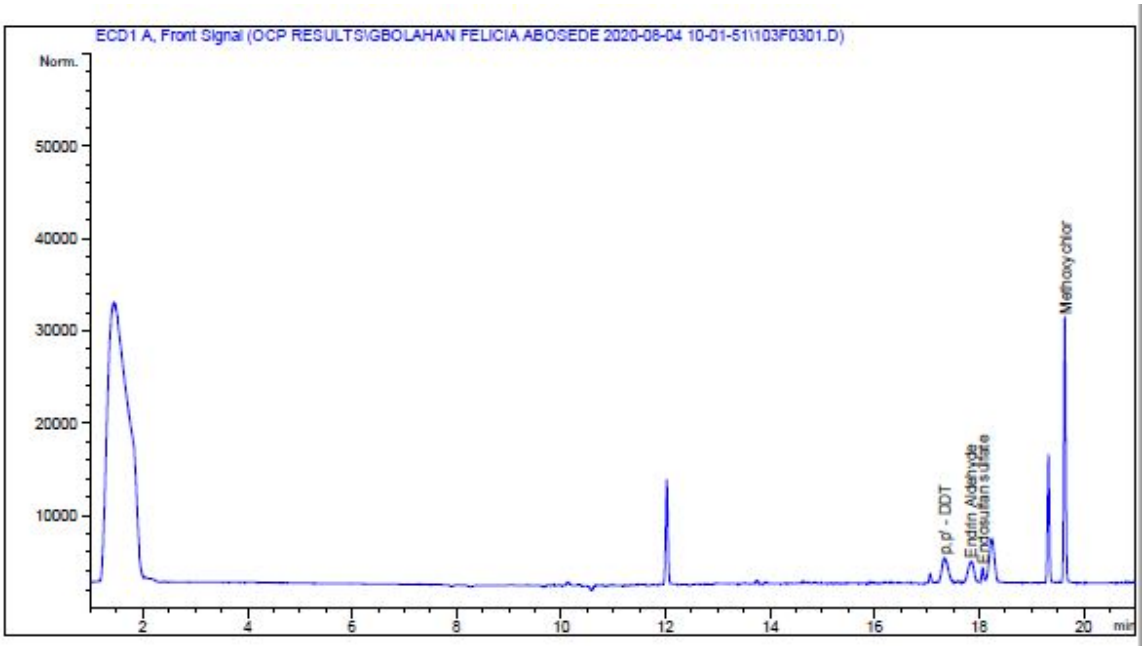
Zhang, H., Liu, N., Han, Z. and Liu, J. 2016. Phylogenrtic analyses and evolutionary timescale of Coleoptera based on Mitochondrial sequence. Biochemical systematics and ecology 66: 229-238.



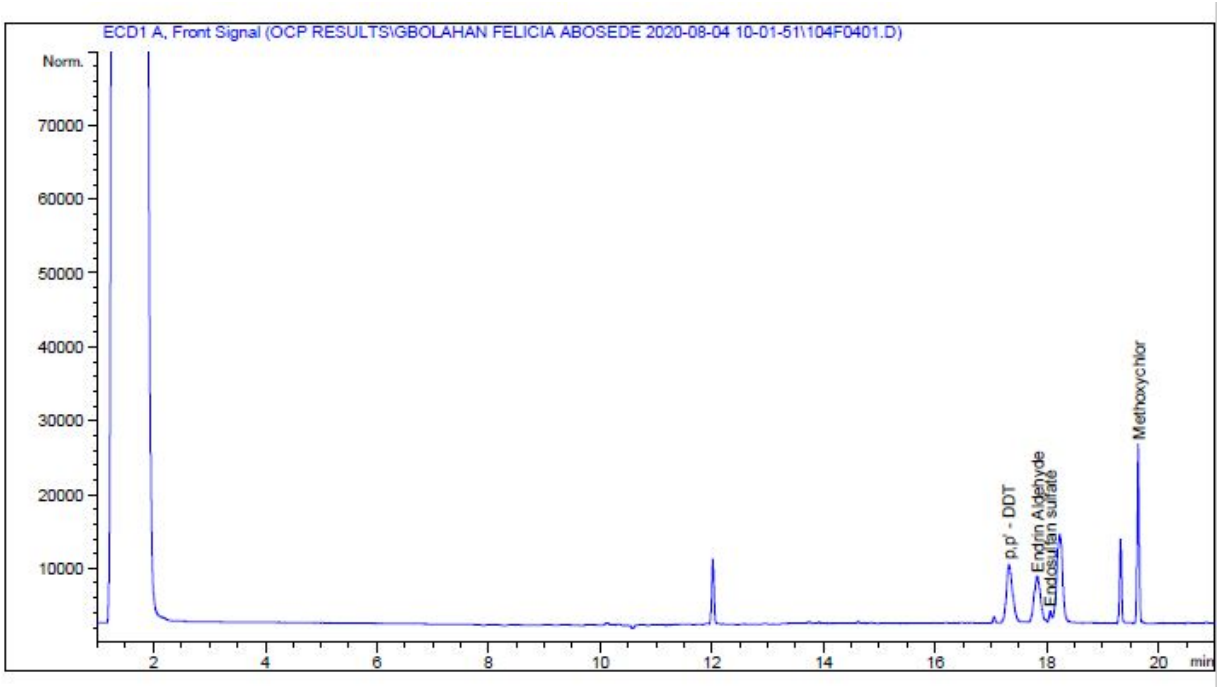
Appendix 1: A Representative Chromatogram of the Osogbo cassava Samples



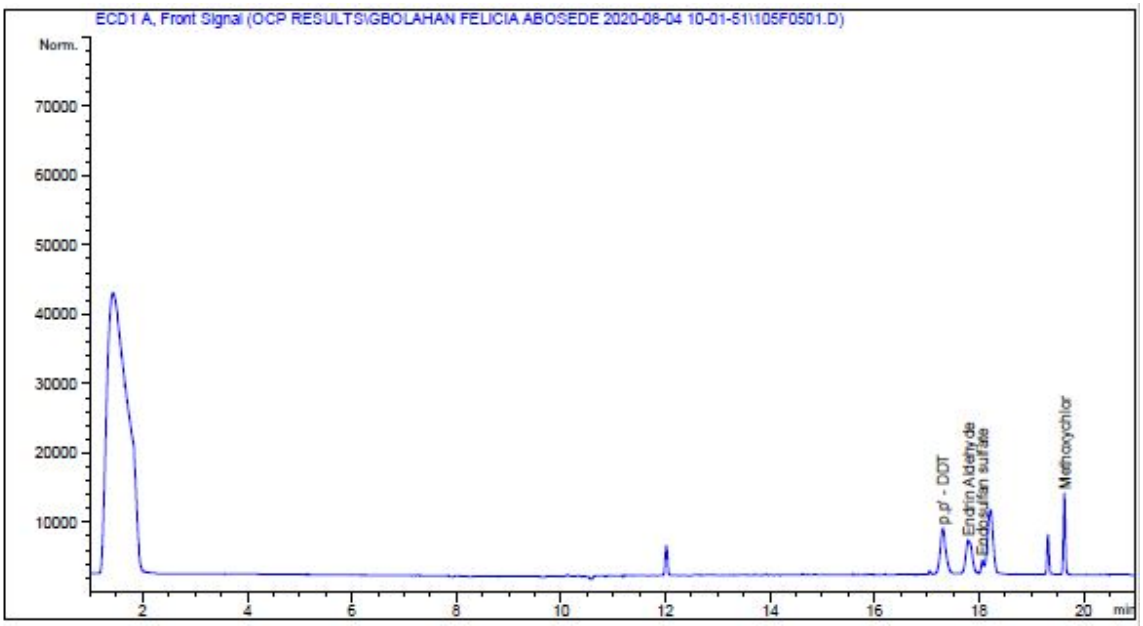
Appendix 2: A Representative Chromatogram of the Ilorin cassava Samples



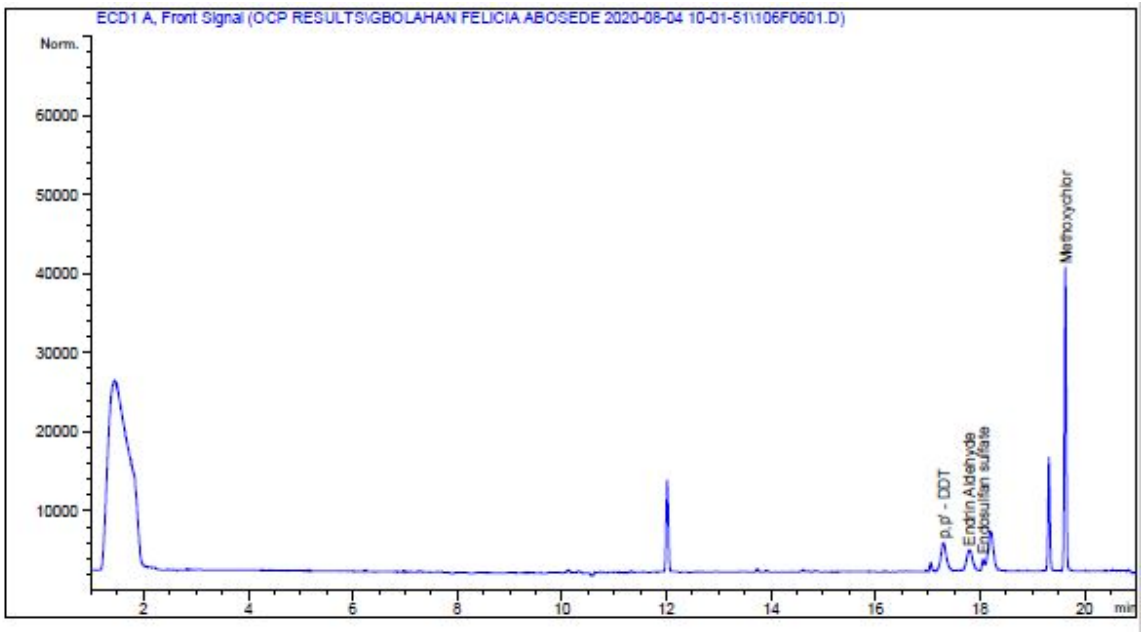
Appendix 3: A Representative Chromatogram of the Osogbo Yam Samples



Appendix 4: A Representative Chromatogram of the Ibadan cassava Samples



Appendix 5: A Representative Chromatogram of the Ibadan yam Samples



Appendix 6: A Representative Chromatogram of the Saki yam Samples