FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE

ECO-FRIENDLY INNOVATIONS: TAPPING INTO PLANT-DERIVED INSECTICIDES FOR STORED PRODUCT PEST CONTROL

199TH INAUGURAL LECTURE SERIES

Delivered by

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Eco-friendly Innovations in Plant-Derived Insecticides for Stored Product Pest Control

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PREAMBLE

It is with immense gratitude to the Almighty God, the Alpha and Omega, the giver of knowledge, wisdom and understanding that I stand before this audience to deliver this lecture. I give all the glory, honour and adoration to God who made it possible for me to witness my 60th birthday on 19th May, and also stand before you today, May 26th, 2026. This is the 199th Inaugural Lecture of the Federal University of Technology, Akure, the first female and the 9th Inaugural lecturer in the Department of Crop, Soil and Pest Management, School of Agriculture and Agricultural Technology Akure, Nigeria.

Madam Vice Chancellor, it is with a sense of fulfilment that l stand before this august audience today to deliver this Inaugural Lecture titled **"Eco-friendly Innovations: Tapping into Plant-Derived Insecticides for Stored Product Pest Control"**.

1.0 INTRODUCTION

My Sojourn into Plant-Derived Insecticides in Stored Product Pest Management.

My academic journey dates back to my undergraduate days between 1987 and 1990 at the University of Ilorin, Ilorin, Nigeria. During this period, my interest in Economic Botany was ignited, particularly through exposure to the harvesting and use of botanicals from forest zones around the University environment. My academic mentor, Professor S. O. Oladele (Late), formally introduced and guided me into the field of Economic Botany. Under his mentorship, I developed a strong interest in plant botanicals and their applications in stored-product pest control. Due to family circumstances that necessitated relocation, I moved to the Federal University of Technology, Akure (FUTA), where I continued my

academic career in the Department of Biology at The Federal University of Technology Akure, I was further nurtured academically under the mentorship of Professor C. O. Adedire and Professor O. O. Odeyemi (Rtd). Their guidance laid a solid foundation for my specialization in stored-product pest control and culminated in my being among the first set of Master of Technology (M.Tech) graduates in the Department of Biology in 1995. A pivotal moment in my academic development occurred when Professor O. O. Odeyemi (Rtd) directed me to the University bookshop to purchase a book titled **"Outlines and Pictures of Medicinal Plants from Nigeria"** authored by Professor Tolu Odugbemi. This book became a major reference and guide that firmly anchored my research interest in plant-derived insecticides and their application in stored-products pest management. To become fully established as a stored-products entomologist within the broader discipline of Agriculture, I later pursued doctoral training under the mentorship of Professor T. I. Ofuya and Professor R. D. Aladesanwa in the Department of Crop, Soil and Pest Management, School of Agriculture and Agricultural Technology of The Federal University of Technology, Akure. Ondo State.

2.0 STORED PRODUCT PESTS AND THEIR SOCIO- ECONOMIC IMPORTANCE

Stored-product pests are insects that infest harvested and stored agricultural commodities such as cereals, legumes, and processed foods during storage, processing, and marketing (Fields and White, 2002). Major stored product pest species of economic importance include *Callosobruchus maculatus, Sitophilus zeamais, Tribolium castaneum, Rhyzopertha dominica and Dinoderus porcellus* (Table1) (Arthur, 1996) (Plate 1-6). Images of some common stored produce insects are shown in Plates 9 to 14. These pests cause substantial quantitative and qualitative

losses, leading to reduced grain weight, nutritional deterioration, and contamination (Fields and White, 2002). Infestation further results in the presence of insect fragments, excreta, webbing, and fungal growth, thereby lowering market value and posing health challenges such as allergies and food poisoning (Subramanyam *et al*., 2016).The combined effects of yield loss and quality reduction aggravate food insecurity and threaten the livelihoods of farmers and grain merchants, particularly in developing countries (Arthur,1996).

Table 1. Major examples of stored product pests.

Pest species	Common name	Commodity attacked
Sitophilus zeamais	Maize weevil	Maize, sorghum, rice
Sitophilus oryzae	Rice weevil	Rice, wheat, cereals
Callosobruchus maculatus	Cowpea bruchid	Cowpea, other legumes
Tribolium castaneum	Red flour beetle	Flour, cereals, processed foods
Rhyzopertha dominica	Lesser grain borer	Wheat, rice, maize
Trogoderma granarium	Khapra beetle	Stored grains (quarantine pest)
Plodia interpunctella	Indian meal moth	Dried fruits, nuts, grains
Dinoderus porcellus	Powderpost beetle	Stored-dried yam

Adapted from Hill, 2002

Plate 1: Stored-cowpea beetle (Callosobruchus maculatus)

Plate 2: Stored-rice weevil (Sitophilus oryzae)

Plate 3: Powderpost beetle (Dinoderus porcellus)

Plate 4: Lesser grain borer (Rhyzopertha dominica)

Plate 5: Maize weevil (Sitophilus zeamais)

Plate 6: Red flour beetle (Tribolium castaneum)

Plate 1-6: Source: Shutterstock.com

3.0 LIMITATIONS OF SYNTHETIC INSECTICIDES IN STORED PRODUCT PROTECTION

The control of stored-product insects has traditionally relied on synthetic chemical insecticides such as phosphine fumigants and organophosphates (Flinn, 2007). Although these chemicals provide rapid and effective pest suppression, their repeated use has resulted in the development of resistance in many stored-product insect populations (Reddy and Kriticos, 1997). Synthetic insecticides are also associated with health hazards to applicators and consumers due to acute toxicity and residual contamination of food commodities (Isman, 2006). Additional constraints include environmental pollution, persistence in the ecosystem, resurgence of pest populations, and adverse effects on non-target organisms (Berger, 1994; Akinkurolere *et al.*, 2006). These challenges have raised serious concerns regarding food safety, trade restrictions, and sustainability of chemical-based pest management strategies (Isman, 2006).

4.0 BOTANICAL INSECTICIDES: TRADITIONAL KNOWLEDGE AND BIOACTIVE PRINCIPLES

Plant derivatives in form of powders, extracts, and oils have been used for centuries by farmers as protective agents against storage insects before the advent of synthetic insecticides (Zibaee, 2011) (Plate 7-14).Such botanicals are known to contain diverse

phytochemicals with insecticidal activity, including alkaloids, terpenoids, phenolics, and essential oils (Isman, 2000:Isman, 2006:Pavela, 2016:Shaalan *et.al*., 2005). These secondary metabolites exert their effects through repellency, feeding deterrence, oviposition inhibition, growth disruption, and reduced fecundity (Shaaya *et al*., 1997).They may also interfere with insect nervous systems, respiration, and reproductive physiology, thereby limiting pest colonization and population build-up in stored products (Nonga, 2009; Isman, 2020).Consequently, numerous plant species have been scientifically evaluated and confirmed to possess insecticidal activities against major stored-product pests (Table 2) (Regnault-Roger *et al*., 2012).

Table 2: Examples Of Some Major Plant-Derived Insecticides

Plant Name	Active ingredients	Mode of Action	Target insects
Azadirachta indica (Neem)	Azadirachtin, salannin	Antifeedant, growth regulator, sterilant	*Sitophilus spp*., *Callosobruchus maculatus*
Pyrethrum chrysanthemum	Pyrethrins	Neurotoxic (sodium channel disruption)	Mosquitoes, beetles, moths
Nicotiana tabacum (Tobacco)	Nicotine	Neurotoxic (acetylcholine receptor agonist)	Aphids, beetles
Syzygium aromaticum Cloves	Eugeneol	Repellant	*Sitophilus spp*, *Callosobruchus maculatus*
Capsicum annuum (Chilli pepper)	Capsaicinoids	Repellent, feeding deterrent	Weevils, bruchids
Piper nigrum (Black pepper)	Piperine	Toxicant, metabolic inhibitor	Stored-grain beetles
Ocimum gratissimum (African basil)	Eugenol, thymol	Fumigant, repellent	*Sitophilus spp, Tribolium spp.*
Lantana camara	Lantadene A & B	Toxicant, antifeedant	Storage and field pests
Citrus spp. (Citrus peels)	Limonene, linalool	Contact toxicity, fumigant	Beetles, moth larvae

Adapted from Isman, 2020

Plate 7: Chilli Pepper.
Capsicum frutescens

Plate 8: Bell Pepper.
Capsicum annum

Plate 9: Beef Steak Plant.
Acalypha wilkesiana.
Copperleaf

Plate 10: Green Acalypha.
Acalypha godseffiana

Plate 11: Scent Leaf.
Ocimum gratissimum.

Plate 12: Pepper Fruit.
Dennettia tripetala

Plate 13:Bitter gourd
Momordica charantia.

Plate 14:Soursop.
Annona muricata.

Plate 7-14: Pictorial examples of some plants whose derivatives are used in stored products pest protection.

Source: Reasearch gate

5.0 MODERN DEVELOPMENTS, INTEGRATION AND THE FOCUS OF THE INAUGURAL LECTURE.

Early applications of plant-derived insecticides were constrained by problems of standardization, short residual activity, volatility, and variability in efficacy due to plant source and extraction method (Isman, 2006; Arnason *et al*., 1989). Recent advances in formulation science, including encapsulation and nanotechnology, have significantly improved the stability, bioavailability and shelf life of botanical insecticides (Melo *et al*., 2021). Integration of plant-based insecticides with physical methods such as solar heating, hermetic storage with biological control, enhance overall pest suppression within the framework of Integrated Pest Management (IPM) (Tefera and Mugo, 2011). Adoption of these technologies by farmers is influenced by

awareness, cost, availability, and extension services (Njoroge *et al*., 2013). Plant-derived insecticides are characterized by low mammalian toxicity, rapid biodegradation, and minimal non-target effects, making them environmentally compatible alternatives to synthetic chemicals (Isman, 2006). Policy frameworks increasingly advocate the incorporation of botanicals into sustainable stored-product pest management programmes (Regnault-Roger *et al*., 2012).

Madam Vice-Chancellor, my inaugural lecture presents a comprehensive synthesis of over a decade of my scholarly contributions to the development and application of plant-derived insecticides as eco-friendly and scientifically validated tools for the control of stored-product pests. Drawing on extensive experimental research, the lecture documents advances in botanical efficacy validation, formulation development, fumigant and contact toxicity evaluation, and the elucidation of biochemical and enzymatic modes of action. It further examines the influence of environmental and biological modifiers on pest responses, thereby strengthening the understanding of variability in insect susceptibility under storage conditions. Through systematic laboratory bioassays, solvent extraction studies, fumigant evaluations, and enzyme-based toxicological analyses, my work demonstrates that botanical insecticides can achieve levels of efficacy comparable to those of conventional synthetic chemicals, while offering superior environmental compatibility and safety. The lecture therefore synthesizes research on the efficacy, formulation, biochemical mechanisms of action, and practical integration of plant-derived insecticides into stored-product pest management systems, establishing them as sustainable alternatives for post-harvest commodity protection (Oni, 2014b).

6.0 MY CONTRIBUTIONS TO KNOWLEDGE

Madam Vice Chancellor, my research over the years made substantial contributions to understanding how environmental and biological variables influence pest development and the effectiveness of plant -derived insecticides. My research group investigated the role of temperature, food substrates, host species and geographical origin in insect growth and development and their tolerance to botanicals. My major contributions to knowledge are highlighted under the following five headings:

(i) Influence of Environment, Host and Agronomic factors on Pest Biology and Control.
(ii) Comparative Efficacy of Indigenous Pepper Plant -Derived Insecticides as Grain Protectants.
(iii) Elucidation of Modes of Action (Enzyme Inhibition and Biomarker Responses).
(iv) Isolation and Validation of Specific Bioactive Compounds.
(v) Efficacy and Toxicological Evaluation of Plant-Derived Insecticides against Major Grain Pests.

6.1. Influence of Environment, Host, and Agronomic Factors on Pest Biology and Control

Madam Vice Chancellor, I present my contributions to research activities in my foundational studies on the influence of host species on the developmental biology of *Dinoderus porcelus* reared on four dried species (Plate 15-17) of yam *Dioscorea alata* (water yam), *D. rotundata* (white yam) , *D. dumetorum* (wild yam) and *D. cayenensis* (yellow yam) (Adedire and **Oni**, 1998). More eggs were laid in *D. dumetorum* (175 ± 12.45 eggs) than other yam species in the no-choice test. In the free-choice test, the highest oviposition were recorded on *D. rotundata* (50 ± 3.67) and the

lowest (30 ± 2.81 eggs) in *D. cayenensis.* (Table 3). The average total developmental periods in *D. alata*, *D. rotundata*, *D. dumetorum* and *D. cayenensis* were 35.25 ± 0.14, 34.75 ± 0.15, 35.50 ± 0.16 and 40.50 ± 0.10 days, respectively (Table 4). The host-species significantly affect oviposition and development of *D. porcellus*, the low oviposition preference for *D. cayenensis* and prolonged developmental period of *D. porcellus* in this yam specie may be due to the presence of some oviposition deterrents and anti-nutritional factors in the yellow yam which may be involved in its protection against the yam beetle attack.

Plate 15: White dried yam

Plate 16: Dried Yellow yam

Plate 17: Dried Wild yam

Source: Plate 15-17 Research Gate

Table 3. Effect of host species on oviposition by the yam beetle, *D. Porcellus*

Host species	Mean number of eggs laid	
	No-choice test	Free-choice test
D. alata	141.8 ± 3.7a	34.4 ± 0.8a
D. rotundata	169.0 ± 6.5ab	50.0 ± 3.7c
D. cayenensis	174.0 ± 11.5ab	30.0 ± 2.8a
D. dumetorum	175.0 ± 12.5b	41.6 ± 3.5b

Each value is a mean ± standard error of the mean of three replications. Means followed by the same letter(s) within a column are not significantly different at $p > 0.05$ according to Duncan's Multiple Range Test (DMRT).

Table 4. Effect of host species on duration of development of *D. Porcellus*

Host species	Egg incubation (days)	Larval period (days)	Pupal period (days)	Total development period (days)
Dioscorea alata	6.5 ± 0.3^{a}	24.5 ± 0.2^{b}	5.8 ± 0.2^{b}	35.3 ± 0.1^{a}
Dioscorea rotundata	7.0 ± 0.2^{a}	22.0 ± 0.2^{a}	4.3 ± 0.1^{a}	34.8 ± 0.2^{a}
Dioscorea cayenensis	6.3 ± 0.2^{a}	28.3 ± 0.1^{c}	6.0 ± 0.2^{b}	40.5 ± 0.1^{b}
Dioscorea dumetorum	7.8 ± 0.2^{b}	22.0 ± 0.2^{a}	5.8 ± 0.1^{b}	35.5 ± 0.2^{a}

Each value is a mean ± standard error of the mean of four replicates. Means followed by the same letter(s) within a column are not significantly different at $p > 0.05$ according to Duncan's multiple range test.

In another study, **Oni** and Omoniyi (2012) evaluated the influence of temperature on oviposition and development of immature stages of the yam beetle *D. porcellus* exposed to various temperature regimes 10 , 15 , 20 , 30 , 35 and 40^{o} C respectively. The four dried yam species were used to determine the effect of temperature on oviposition and developmental stages of the insect. At 10^{o}C, there was no oviposition, at 15^{o}C fewer eggs were laid. Oviposition increased with little variation as temperature increased from 20-30^{o} C while the number of eggs laid reduced at 35 ^{o}C and no oviposition was observed at 40^{o} C (Table 5). Egg incubation period ranged 6 -8 days and there were significant differences ($p<0.05$) in the developmental period of larva but no significance difference ($P<0.05$) at the pupal stage.

(Fig. 1). The developmental period was prolonged in *D. cayenensis* as temperature increases (Adedire and **Oni,** 1998). It was apparent from our studies that temperature plays a critical role in determining oviposition rates and development of immature stages of storage insects thereby influencing infestation dynamics and control outcomes.

Table 5. Mean egg number (mean ± se) oviposited by female *Dinoderus porcellus* on dried yam species at different temperatures

Dried yam species	10 °C	15 °C	20 °C	25 °C	30 °C	35 °C	40 °C
Dioscorea rotundata	–	21.5 ± 1.19^{b}	25.0 ± 1.03^{ab}	33.5 ± 1.32^{a}	35.0 ± 0.41^{a}	34.0 ± 2.16^{a}	–
Dioscorea alata	–	20.75 ± 1.38^{c}	26.75 ± 0.85^{b}	33.5 ± 1.89^{a}	32.75 ± 1.89^{a}	32.75 ± 1.89^{a}	–
Dioscorea dumetorum	–	19.75 ± 0.63^{c}	24.5 ± 0.65^{b}	31.25 ± 1.11^{a}	32.25 ± 2.01^{a}	29.0 ± 0.91^{b}	–
Dioscorea cayenensis	–	6.5 ± 1.19^{a}	9.25 ± 0.85^{a}	8.5 ± 1.11^{a}	9.25 ± 1.11^{a}	7.25 ± 1.11^{a}	–

Each value is a mean of 4 replicates standard error of the mean. Means followed by the same letter(s) are not significantly different ($p>0.05$) by New Duncan's multiple range test.

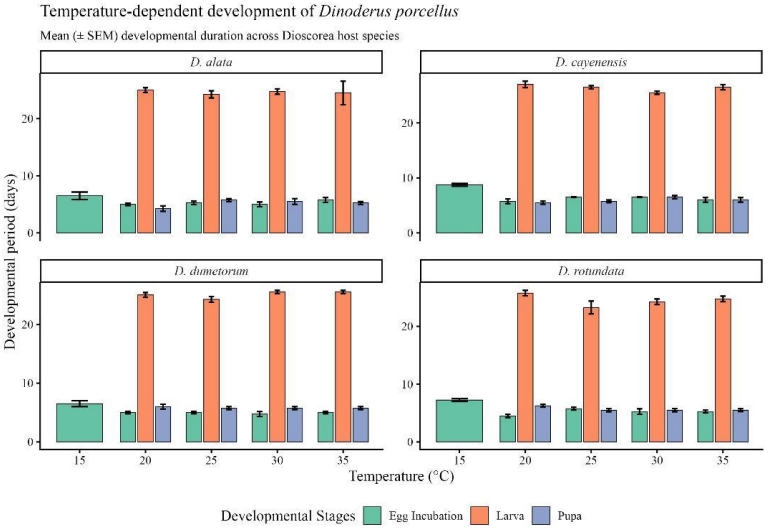

Fig. 1

Madam Vice Chancellor, I am happy to unveil from my research contributions that both biotic and abiotic factors have effect on the response of insects to plant -derived insecticides. **Oni** *et al*., (2016a): Lamidi and **Oni,** (2025) reported that, food type and geographical variations on the tolerance of *Callosobruchus maculatus* to oil extract of (*Fagara xanthoxyloides*) (african pepper chewing stick) (Plate 18) on insects collected from four different states within the southwestern region of Nigeria fed with Ife-Brown and IT96-610 cowpea variety showed differential tolerance of *C. maculatus* populations to the oil extract on adult survival and immature developmental stages (Tables 6). The insect fed with 1196-610 variety appeared to be significantly tolerant to oil extracts (Tables 7 & 8), while insects from Osun State also showed

more tolerance to than those from other three locations. Our findings emphasised the importance of location-specific and commodity- specific pest management strategies.

Plate 18*: Fagara xanthoxyloides,*

Source: Research gate

Table 6. Interactive effect of food type, geographical location and dosages of *F. xanthoxyloides* on adult survival and immature stages of *C. maculatus* and its ability to cause seed damage and weight loss

Cowpea variety	Location	Conc (%)	72 h Mortality (%)	Oviposition (%)	Adult emergence (%)
Ife-Brown	Akure	1	57.50 ± 0.25ef	33.50 ± 1.55d	2.00 ± 0.41a
		2	90.50 ± 0.75gh	25.00 ± 0.91c	0.00 ± 0.00a
		4	100.00 ± 0.25h	17.25 ± 0.63b	0.00 ± 0.00a
	Osun	1	17.50 ± 0.25ab	53.50 ± 1.94f	13.75 ± 1.49d
		2	37.50 ± 0.25c	43.50 ± 1.32e	9.25 ± 0.85bc
		4	85.00 ± 0.29g	28.25 ± 2.63cd	10.75 ± 0.85cd
	Lagos	1	30.00 ± 0.40c	49.25 ± 4.06ef	11.75 ± 0.85d
		2	50.50 ± 0.25e	36.25 ± 3.33de	17.75 ± 1.25b
		4	97.50 ± 0.25h	17.75 ± 1.25b	1.25 ± 0.63a
	Ogun	1	22.50 ± 0.25b	51.25 ± 2.78f	8.75 ± 1.31bc
		2	32.00 ± 0.41c	35.50 ± 0.65d	2.75 ± 0.85a
		4	97.50 ± 0.00h	26.75 ± 0.48c	0.00 ± 0.00a
IT96-610	Akure	1	40.00 ± 0.28cd	53.54 ± 0.64f	10.54 ± 1.45cd
		2	78.50 ± 0.32g	45.58 ± 0.58e	9.64 ± 0.87c
		4	86.00 ± 0.22gh	40.94 ± 1.12e	6.75 ± 2.08b

Cowpea variety	Location	Conc (%)	72 h Mortality (%)	Oviposition (%)	Adult emergence (%)
	Osun	1	12.00 ± 0.00a	68.82 ± 2.13g	20.64 ± 2.23g
		2	22.50 ± 1.22b	60.45 ± 1.43g	18.43 ± 1.48g
		4	68.50 ± 0.34f	56.67 ± 1.34fg	15.55 ± 2.12f
	Lagos	1	22.00 ± 0.21b	56.86 ± 0.98fg	15.67 ± 1.56f
		2	42.00 ± 0.88cd	52.64 ± 1.43f	13.23 ± 0.67ef
		4	76.00 ± 0.67f	48.86 ± 2.14ef	11.56 ± 2.14de
	Ogun	1	24.00 ± 0.24b	50.45 ± 1.23f	10.42 ± 1.45cd
		2	40.00 ± 0.33cd	45.14 ± 1.45ef	5.42 ± 2.32b
		4	78.00 ± 0.24g	40.54 ± 2.32e	2.46 ± 1.76a
Ife-Brown	Reference	1	88.50 ± 0.22g	20.26 ± 0.88bc	0.00 ± 0.00a
		2	100.00 ± 0.00h	18.74 ± 1.24b	0.00 ± 0.00a
		4	100.00 ± 0.00h	8.76 ± 0.68a	0.00 ± 0.00a
IT96-610	Reference	1	74.50 ± 0.13f	33.56 ± 1.33d	2.34 ± 0.21a
		2	86.00 ± 0.24g	23.58 ± 0.43c	1.20 ± 1.23a
		4	100.00 ± 0.00h	14.21 ± 1.21ab	0.00 ± 0.00a

Each value is mean and standard error of five replicates. Values followed by the same alphabet in the same column are significantly ($P < 0.05$) different from each other using Duncan's multiple range test

Table 7. Lethal concentration of *F. xanthoxyloides* oil and the corresponding tolerance ratio of *C. maculatus* from different locations fed with Ife-brown cowpea variety

Locations	Slope	Intercept	X^2	LC_{50} (95 FL)	LC_{95} (95 FL)	TR_{50}	TR_{95}
Akure	3.72±0.25	-0.61±0.07	0.30	1.46(1.37-1.54)	4.03(3.60-4.63)	1.78	2.60
Osun	2.21±0.24	-1.02±0.08	7.87	2.90(2.60-3.36)	8.12(6.06-10.56)	3.54	5.24
Lagos	2.56±0.23	-0.90±0.08	12.93	2.25(1.98-2.64)	9.90(6.70-17.89)	2.74	6.39
Ogun	2.90±0.24	-0.96±0.08	9.19	2.32(1.98-2.64)	8.57(5.83-17.91)	2.83	5.53
Reference	5.90±0.69	0.52±0.08	2.57	0.82(0.23-0.88)	1.55(1.43-1.75)	1.00	1.00

X^2: Chi-square; SE: Standard error; FL: Fiducial limits; LC: Lethal concentration (%); TR: Tolerance ratio

Table 8. The lethal concentration of *F. xanthoxyloides* oil and the corresponding tolerance ratio of *C. maculatus* from different locations fed with IT96-610 cowpea variety

Locations	Slope	Intercept	X^2	LC_{50} (95 FL)	LC_{95} (95 FL)	TR	TR_{50}	TR_{95}
Akure	3.69±0.25	-0.98±0.08	8.65	1.84(1.74-1.95)	5.14(4.80-6.53)	1	2.67	1.18
Osun	1.95±0.27	-1.44±0.10	6.08	5.50(4.34-8.22)	12.58(9.26-112.38)		7.97	2.44
Lagos	2.80±0.24	-0.92±0.08	15.09	2.36(2.08-2.81)	8.27(5.82-15.43)		3.42	1.91
Ogun	3.14±0.24	-0.98±0.08	18.11	2.21(1.95-2.57)	7.38(5.34-15.31)		3.20	1.70
Reference	2.06±0.25	-0.33±0.07	4.36	0.69(0.51-0.83)	4.34(3.51-6.04)		1.00	1.00

X^2: Chi-square; SE: Standard error; FL: Fiducial limits; LC: Lethal concentration

Oni, Ogungbite and Yusuff (2018a): **Oni** *et al*. (2018b) observed the effect of temperature ranges on insecticidal potency of *Acalypha godseffiana* oil against cowpea beetle *C. maculatus.* The oil was divided into five portions; the first four portions were exposed to temperatures 30, 40. 50 and 70^0C, while the fifth portion (control) was only exposed to the ambient laboratory at a temperature of 28 ± 2^0C. We reported that, (Table 9: Fig.2) effectiveness of the oil decreased with increase in temperature. In addition, the quantity of the phytochemicals in the oil decreased with increase in temperature. We suggested that under moderate temperature, the oil of *A. godseffiana* was more effective in the control of the cowpea beetle, but under high temperature, it became ineffective due to damage (Fig. 3) caused by high temperature to botanical phytochemicals (**Oni** *et al.*, 2018a: Dougoud *et al*., 2019).

Table 9. Interactive effect of temperature and concentration on mortality effect of *A. godseffiana* on *C. maculatus*.

Period (hours)	Temp (°C)	Mortality ± SE	Conc. (%)	Mortality ± SE	Sig. level
24	0	11.67 ± 1.55d	2	2.67 ± 1.20a	0.561
	30	7.78 ± 1.55cd			
	40	5.56 ± 1.55c	4	6.00 ± 1.20ab	
	50	4.44 ± 1.55ab			
	70	1.03 ± 1.55a	6	9.80 ± 1.20c	
48	0	28.89 ± 1.51a	2	9.67 ± 1.17a	0.056
	30	21.67 ± 1.51b			
	40	15.00 ± 1.51c	4	16.33 ± 1.17b	
	50	10.56 ± 1.51d			
	70	1.11 ± 1.51e	6	20.33 ± 1.17c	

72	0	56.67 ± 1.41a	2	21.67 ± 1.09a	0.002
	30	47.22 ± 1.41b			
	40	25.00 ± 1.41c	4	29.33 ± 1.09b	
	50	14.44 ± 1.41d			
	70	1.11 ± 1.41e	6	35.67 ± 1.09c	
96	0	80.00 ± 1.47a	2	35.67 ± 1.14a	0.000
	30	71.11 ± 1.47b			
	40	46.11 ± 1.47c	4	41.33 ± 1.4b	
	50	18.33 ± 1.47d			
	70	1.11 ± 1.47e	6	53.00 ± 1.4c	

Values followed by the same alphabet are not significantly ($p>0.05$) different from each other using New Duncan's

Multiple Range Test.

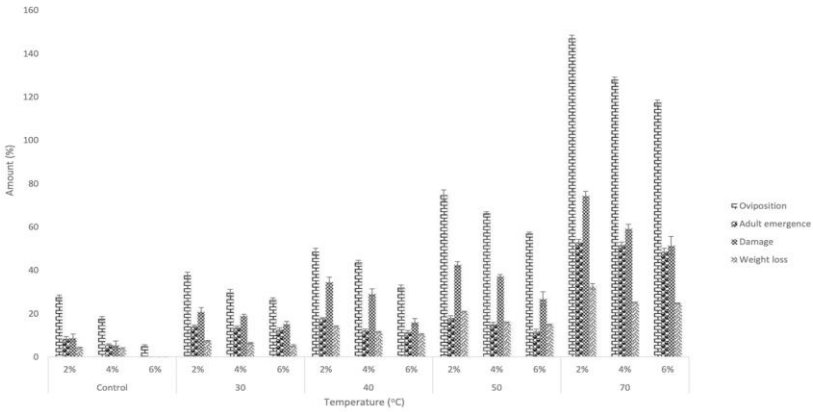

Fig. 2. Oviposition and adult emergence of *C. maculatus* as well as the damage and weight loss of protected cowpea seeds. Values are the mean of three replicates.

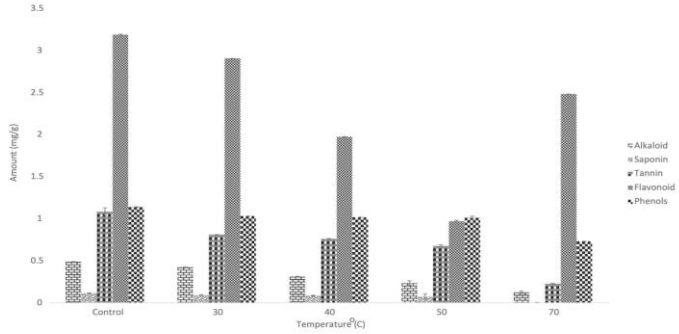

Fig. 3. Phytochemical composition of *A. godseffiana* leaves oil exposed to different temperature level.

6.2 Comparative Efficacy of Indigenous Pepper-Derived Insecticides as Grain Protectants.

Madam Vice Chancellor, my research group explored the potential of pepper cultivars, formulations as powders, oils extracts and pest responses, establishing indigenous pepper plants as effective grain protectants.

Oni, Ofuya and Aladesanwa, 2010a; **Oni (**2014a) reported three capsicum species cultivars namely; Cayenne pepper (Atarodo), Sweet pepper (Tatase) and long cayenne pepper (Sombo) (Plate 21-23) extracts from three organic solvents (hexane, ethanol and acetone) tested on cowpea seed beetle *Callosobruchus maculatus* for insecticidal activity. Extracts from cayenne pepper were the most effective in reducing oviposition, adult emergence, seed damage and seed weight loss followed by long-cayenne pepper and sweet pepper (Table 10). Hexane proved to be the best extracting solvent in terms of efficacy, followed by ethanol and acetone. Hexane extracts of cayenne pepper at all dosages tested proved effective with 100% adult mortality and lowest seed damage (Table 11). Specifically, extracts from cayenne and long cayenne pepper showed 51-95% seed germination, while seed germination inhibition occurred at all rates of extracts from sweet-pepper. However, all Capsicum extracts across tested concentrations were potent bioinsecticide against the seed bruchid by protecting stored cowpea (Plate 19-20) and maize seeds over a period of three months (Tables 12 and13) and six months consecutively (**Oni**, 2010b).

Plate 19: *Treated Cowpea*

Plate 20: Infested Cowpea

Source Plate 19 & 20: *Researchgate*

Table 10. Combined interaction of cultivar, solvent and concentration on *C. maculatus* development, seed damage and weight loss in cowpea

Cultivar	Solvent	Conc. ml/20g Seed	Mean no of eggs	Mean % F_1 Adult emerged	Mean % Seed damage	Mean % weight loss	Mean % adult mortality
Atarodo	Hexane	SC	271.5d	81.3c	83.3d	14.1c	3.62n
		UC	287.4a	90.05a	91.75a	15.9a	2.85n
		0.5	0.00Z	0.00v	0.09u	0.04l	100.0a
		1.0	0.00Z	0.00v	0.06u	0.01l	100.0a
		2.0	0.00Z	0.00v	0.00u	0.01l	100.0a
		5.0	0.00Z	0.00v	0.00u	0.01l	100.0a
		10.0	$0.00Z_2$	0.00v	0.00u	0.01l	100.0a
	Ethanol	SC	274.2c	85.75b	86.2c	14.6b	3.11n
		UC	284.4a	90.05a	91.75a	15.9a	2.85n
		0.5	13.50v	4.65q	1.13pqr	0.17ijkl	100.0a
		1.0	10.0v	3.00rst	1.02pqr	0.14ijkl	100.0a
		2.0	5.00y	1.75tuv	0.41stu	0.07kl	100.0a
		5.0	3.75z	1.52uv	0.37stu	0.07kl	100.0a
		10.0	$1.40z_1$	1.05v	0.12u	0.03l	100.0a
	Acetone	SC	82.5b	89.2a	90.0b	14.85a	2.95n
		UC	287.4a	90.05a	91.75a	15.9a	2.85n
		0.5	16.75s	6.850	1.37p	0.38i	100.0a
		1.0	15.75t	5.25pq	1.31pq	0.33ij	100.0a
		2.0	7.00x	2.75rstu	0.84qrs	0.12jkl	100.0a
		5.0	6.25x	1.85stuv	0.48stu	0.08kl	100.0a
		10.0	4.25yz	1.70tuv	0.16tu	0.04l	100.0a
Tatase	Hexane	SC	271.5d	81.3c	83.3d	14.1c	3.62n
		UC	287.4a	90.05a	91.75a	15.9a	2.85n
		0.5	38.0h	15.4fl	5.64k	0.76gh	12.5lmn
		1.0	29.0kl	2.3hi1	5.56k	0.74gh	20.1ijkl
		2.0	25.0m	0.01jkl	5.20k	0.72gh	25.65ghij
		5.0	20.0pq	8.75lm	4.39l	0.69h	29.45fghi
		10.0	8.75w	8.50mn	3.47m	0.61h	36.5ef
	Ethanol	SC	274.2c	85.75b	86.2c	14.6b	3.11n
		UC	287.4a	90.05a	91.75a	15.9a	2.85n
		0.5	40.0g	17.55e	11.8g	1.53e	7.50mn
		1.0	32.5i	14.22fg	11.2h	1.48e	18.75j
		2.0	29.5jk	11.95hi	9.95i	1.02f	23.0hijk
		5.0	28.25l	10.4jk	7.41j	0.94fg	26.42fghij
		10.0	19.05r	9.25klm	5.60k	0.75gh	34.0efg
	Acetone	SC	282.5b	89.2a	90.0b	14.85a	2.95n
		UC	287.4a	90.05a	91.75a	15.9a	2.85n
		0.5	49.5e	19.95d	16.8e	2.01d	5.75mn
		1.0	41.75f	16.65e	14.45f	1.96d	11.25lmn
		2.0	39.25g	14.2fg	11.11h	1.36e	16.25klm
		5.0	30.0j	13.0gh	10.01i	1.08f	18.5jkl
		10.0	28.2l	12.05hi	7.30j	0.92fg	27.4fghi
Sombo	Hexane	SC	271.5d	81.3c	83.3d	14.1c	3.62n
		UC	287.4a	90.05a	91.75a	15.9a	2.85n
		0.5	6.50x	3.25rs	1.19pqr	0.19ijkl	100.0a
		1.0	5.00y	2.92rstu	1.05pqr	0.14jkl	100.0a
		2.0	$1.78z_1$	1.12v	0.17tu	0.05kl	100.0a
		5.0	$1.55z_1$	1.09v	0.10u	0.05kl	100.0a
		10.0	$1.45z_1$	1.07v	0.07u	0.02l	100.0a

Ethanol	SC	274.2c	85.75b	86.2c	14.6b	3.11n
	UC	287.4a	90.05a	91.75a	15.9a	2.85n
	0.5	20.0pq	6.40op	1.32pq	0.33ij	75.0c
	1.0	18.75r	5.22pq	1.20pqr	0.21ijkl	87.5b
	2.0	13.5v	5.05pq	0.65rst	0.12jkl	96.25ab
	5.0	11.75v	4.00qr	0.27tu	0.08kl	100.0a
	10.0	10.25u	2.60rstu	0.15tu	0.04kl	100.0a
Acetone	SC	282.5b	89.2a	90.0b	14.85a	2.95n
	UC	287.4a	90.05a	91.75a	15.9a	2.85n
	0.5	24.0n	11.35ij	2.25n	0.38i	32.5fgh
	1.0	21.5o	9.00lm	2.00no	0.34ij	42.5de
	2.0	19.25qr	7.35no	1.96no	0.33ij	50.0d
	5.0	20.75op	6.20op	1.52op	0.28ijk	77.5c
	10.0	13.25v	3.25rs	1.03pqr	0.14jkl	87.5b

Means in all rows and columns followed by the same letters) are not significantly different ($p>0.05$) from each other using Duncan's Multiple Range Test.

Table 11. Effects of pepper cultivars on the development of *C. maculatus*, seed damage and weight loss in cowpea seeds

Cultivar	Mean no of eggs on treated seeds	Mean % Fl adults from eggs laid	Mean % seed damage after Fl emergence	Mean % weight loss by *C. maculatus*	Mean % adult mortality of *C. maculatus*
Atarado	10.62c	2.03c	0.49c	0.10c	100.00a
Tatase	30.58a	12.95a	8.66a	1.1 la	20.87c
Sombo	13.58b	4.69b	0.99b	0.18b	87.5b

Means in each column followed by the same letter are not significantly different ($p>0.05$) from each other, using Duncan's Multiple Range Test

Table 12. Interaction effects of *Capsicum* extracts on germination of treated cowpea seeds

Cultivar	Solvent	Solvent Control	Untreated Control	Concentration(ml/20 g seeds)				
				0.5	1.0	2.0	5.0	10.0
Atarodo	Hexane	98.65b	100.0a	73.0j	77.8h	87.25e	95.0c	81.25f
	Ethanol	98.0b	100.0a	74.4i	74.35i	86.65e	91.35d	80.0g
	Acetone	95.25c	100.0a	68.4kl	68.6kl	69.5k	72.0j	68.65kl
Tatase	Hexane	98.65b	100.0a	48.55v	44.5x	42.85y	38.4z_1	28.35z_4
	Ethanol	98.0b	100.0a	46.2w	43.75y	39.65z	35.0z_2	26.45z
	Acetone	95.25c	100.0a	43.0y	41.0z	35.2z_2	32.55z_3	$_5$21.0z_6
Sombo	Hexane	98.65b	100.0a	51.3u	62.5n	63.75m	67.7l	60.65o
	Ethanol	98.0b	100.0a	51.75u	53.75t	58.25p	60.42o	56.25qr
	Acetone	95.25c	100.0a	54.5s	55.15r	58.0p	60.65p	57.1pq

Means in all rows and columns followed by the same letters) are not significantly different ($p>0.05$) from each other using Duncan's Multiple Range Test.

Table 13. Interaction effects of *Capsicum* extracts at different concentrations on treated cowpea seeds stored for 92 days.

Cultivar	Solvent	Control Solvent	Untreated Control	Concentration (ml/20g seed)				
				0.5	1.0	2.0	5.0	10.0
Atarodo	Hexane	60.0a	60.2a	1.30o	1.05o	0.00o	0.00o	0.00o
	Ethanol	60.0a	60.2a	2.25no	2.00o	1.15o	0.00o	0.00o
	Acetone	60.0a	60.2a	4.05lm	3.45mn	2.25no	1.20o	1.10o
Tatase	Hexane	60.0a	60.2a	40.25e	40.0e	40.05e	36.5g	36.0g
	Ethanol	60.0a	60.2a	44.65c	42.76d	38.6f	38.0f	34.7h
	Acetone	60.0a	60.2a	48.6a	48.4b	43.0d	40.75e	40.0e
Sombo	Hexane	60.0a	60.2a	9.25i	4.95L	4.82l	3.35mn	1.24o
	Ethanol	60.0a	60.2a	9.05ij	8.70j	6.45k	4.98l	2.47no
	Acetone	60.0a	60.2a	10.25i	8.48j	8.45j	5.36kl	3.45mn

Means in all rows and columns followed by the same letters are not significantly different at ($p<0.05$) from each other using Duncan's Multiple Range Test.

Plate 21: Long cayenne pepper (Sombo)

Plate22: Bell pepper (Tatase)

Plate 23: Cayenne pepper (Atarodo)

Plate 21-23. Source: Researchgate

Similarly, **Oni, (**2011) reported, responses of *Callosobruchus maculatus* in stored cowpea and *Sitophilus zeamais* in stored maize to *Capsicum annum* and *Capsicum frutescens* fruits and seed powders and found that seed powder (dusts) were consistently effective and toxic to *C. maculatus* and *S. zeamais* survival than fruit powders, thus indicating a higher concentration or potency of bioactive compounds in the seeds (Table 14).

Oni (2014b) reported the entomotoxic efficacy of cayenne pepper, sweet pepper and long cayenne pepper oil extracts on *Sitophilus zeamais* infesting maize (Plate 24-25) and findings showed that oil extracts of cayenne pepper caused consistently high and dose-dependent mortality of *S. zeamais* even after storage, compared to sweet pepper that showed moderate toxicity and long cayenne pepper rapidly lost effectiveness after six months storage (Table 15). However, the effectiveness of all the cultivars of *Capsicum spp*. decreased as the post-treatment storage period increased (Figs. 4 and 5). All treated grains achieved 90% viability at all dosage level except sweet pepper, however were not significantly ($p>0.05$) different from each other.

Furthermore, Rosulu**, Oni**, Ofuya and Adebayo (2022) reported the efficacy of Chilli pepper *Capsicum frutescens* (Plate 26) for the management of cowpea weevil *Callosobruchus maculatus* infesting cowpea in a storage environment. Our findings revealed that chilli pepper significantly suppressed *C. maculatus* infestation in cowpea storage by reducing oviposition, adult emergence and survival. Treated grains recorded minimal weight loss after four months storage with higher germination percentage and preserved proximate composition at 3.0g chilli pepper treatments and was the most effective protectant compared to other tested dosages (Tables 15, 16a, and 16b). An appreciable level of grain protection against stored cowpea damage by *C. maculatus* could be achieved using capsicum powder and whole fruit as it has adverse effect on the insect and no adverse effect on viability of protected seeds.

Plate 24: Infested Maize

Plate 25: Treated Maize

Plate 26: Chilli Pepper

Plate 24-26, Source: Researchgate

Table 14. Combined effect of *Capsicum annum* and *Capsicum frutescens* on Percentage mortality of *Callosobruchus maculatus* and *Sitophilus zeamais*.

Treatment	Dosage (g/50 g seeds)	*C. maculatus* 48 h (%)	*C. maculatus* 96 h (%)	*S. zeamais* 48 h (%)	*S. zeamais* 96 h (%)
Capsicum annuum fruit powder	2.5	10.4^{e}	18.3^{e}	9.5^{e}	10.3^{e}
	5.0	13.3^{e}	18.7^{e}	10.4^{e}	12.5^{e}
	7.5	15.4^{e}	20.4^{e}	11.3^{e}	14.7^{e}
Capsicum annuum seed powder	2.5	22.5^{d}	24.7^{e}	20.5^{d}	25.7^{d}
	5.0	34.2^{c}	45.4^{c}	37.3^{c}	39.3^{c}
	7.5	53.4^{b}	58.3^{b}	50.4^{b}	57.5^{b}
Capsicum frutescens fruit powder	2.5	17.5^{e}	19.3^{e}	13.3^{e}	15.5^{de}
	5.0	22.2^{d}	25.4^{e}	16.5^{e}	16.3^{de}
	7.5	25.4^{d}	39.7^{d}	18.4^{e}	20.7^{d}
Capsicum frutescens seed powder	2.5	37.2^{c}	40.4^{c}	26.4^{d}	37.5^{c}
	5.0	63.5^{a}	67.3^{a}	60.3^{a}	63.7^{a}
	7.5	73.4^{a}	75.7^{a}	68.5^{a}	63.7^{a}
Control	0.0	0.0^{f}	0.0^{f}	0.0^{f}	0.0^{f}

Means within each column followed by the same letter(s) are not significantly different at P>0.05 according to Tukey's Honestly Significant Difference (HSD) test.

Table 15. Toxicity of *Capsicum* powder, whole fruit and actellic dust on immature stages, seed damage and weight loss of *C .maculatus* in 200g stored cowpea seeds

Treatment (rates of *Capsicum* powder/whole fruit)	Mean number of eggs laid/hatched (±SE) at 21 days after infestation	Mean number of adult emergence (±SE) at 38 days after infestation	Percentage adult emergence survival (±SE) at 38 days after infestation	Initial seed weight at commencement of experiment (g)	Cowpea seed weight after 4 months of storage (g) (+SE)	Damage done to cowpea seeds (number of existing holes/perforations after 4 months of storage (±SE)
1.0 g (20%) of *Capsicum* powder (T1)	55.3 ± 8.3c	0.0 ± 0.0a	0.0 ± 0.0a	200a	192.0 ± 1.8cd	378.8 ± 63.9e
2.0 g (35%) of *Capsicum* powder (T2)	55.7 ± 8.3c	0.0 ± 0.0a	0.0 ± 0.0a	200a	193.5 ± 1.8bc	317.8 ± 63.9f
3.0 g (45%) of *Capsicum* powder (T3)	50.2 ± 8.3c	0.0 ± 0.0a	0.0 ± 0.0a	200a	193.9 ± 1.8b	320.6 ± 63.9f
1.0 g whole fruit of *Capsicum* (T4)	70.1 ± 8.3a	0.0 ± 0.0a	0.0 ± 0.0a	200a	193.8 ± 1.8b	481.6 ± 63.9c

Treatment (rates of *Capsicum* powder/whole fruit)	Mean number of eggs laid/hatched (±SE) at 21 days after infestation	Mean number of adult emergence (±SE) at 38 days after infestation	Percentage adult emergence survival (±SE) at 38 days after infestation	Initial seed weight at commencement of experiment (g)	Cowpea seed weight after 4 months of storage (g) (+SE)	Damage done to cowpea seeds (number of existing holes/perforations after 4 months of storage (±SE)
2.0 g whole fruit of *Capsicum* (T5)	66.1 ± 8.3ab	0.0 ± 0.0a	0.0 ± 0.0a	200a	193.2 ± 1.8bc	494.0 ± 63.9b
3.0 g whole fruit of *Capsicum* (T6)	64.2 ± 8.3b	0.0 ± 0.0a	0.0 ± 0.0a	200a	190.9 ± 1.8d	461.0 ± 63.9d
Actellic dust (2%) (T7)	0.0 ± 0.0d	0.0 ± 0.0a	0.0 ± 0.0a	200a	200.0 ± 1.8a	0.0 ± 63.9g
Control (untreated cowpea seed)	75.5 ± 8.3a	60.0 ± 0.0b	40.0 ± 0.0b	200a	181.5 ± 1.8e	596.0 ± 63.9a

Means in all rows and columns followed by the same letters are not significantly different at ($p>0.05$) from each other using Duncan's Multiple Range Test.

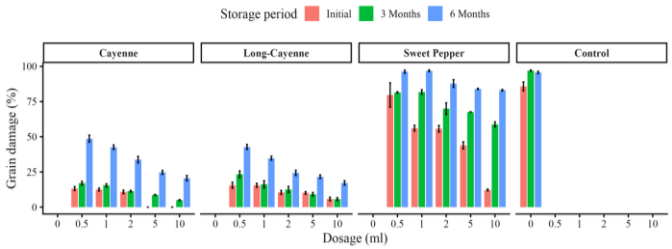

Fig. 4: Percentage of grain damage in maize seeds treated with *Capsicum* extracts

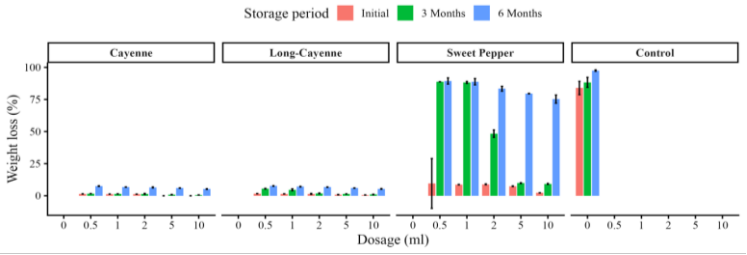

Fig. 5: Percentage weight loss in maize seeds treated with extracts of *capsicum*

Table 16a. Proximate composition of cowpea seeds before infestation

Nutrient (±SE)	Proximate composition of cowpea seeds before infestation (±SE)
Moisture	8.30
Ash	5.13
Fat	2.33
Crude fibre	7.49
Protein	20.51
Carbohydrate	56.24

Table 16b. Proximate composition of cowpea seeds after infestation (± SE)

Treatment	Moisture (%)	Ash (%)	Fat (%)	Crude fibre (%)	Protein (%)	CHO (%)
Cowpea treated with 1 g of *Capsicum* powder (T1)	6.51 ± 0.02e	4.11 ± 0b	1.72 ± 0.10bc	6.01 ± 0.12d	16.01 ± 0.03c	54.39 ± 0.10f
Cowpea treated with 2 g of *Capsicum* powder (T2)	6.91 ± 0.08c	4.12 ± 0.02b	1.81 ± 0.01b	6.31 ± 0.03c	17.90 ± 0.02abc	55.51 ± 0.02b
Cowpea treated with 3 g of *Capsicum* powder (T3)	7.32 ± 0.05b	4.13 ± 0.02b	2.00 ± 0.02a	7.01 ± 0.01b	18.90 ± 0.01ab	53.66 ± 0.10g
Cowpea treated with 1 g of whole fruit of *Capsicum* (T4)	6.31 ± 0.02g	3.63 ± 0.01e	1.45 ± 0.01d	5.01 ± 0.01f	17.50 ± 0.04abc	56.49 ± 0.04a
Cowpea treated with 2 g of whole fruit of *Capsicum* (T5)	6.41 ± 0.04f	3.88 ± 0d	1.52 ± 0.01d	5.31 ± 0e	16.91 ± 0.02bc	54.49 ± 0.14e
Cowpea treated with 3 g of whole fruit of *Capsicum* (T6)	6.64 ± 0.10d	3.98 ± 0c	1.69 ± 0.02c	5.42 ± 0.02e	18.09 ± 0.04abc	55.22 ± 0.02c
Dust (0.1 g) (T7)	8.29 ± 0.02a	5.09 ± 0.03a	2.10 ± 0.05a	7.40 ± 0a	20.02 ± 0.01a	55.07 ± 0.04d

Means in all rows and columns followed by the same letters are not significantly different at ($p>0.05$) from each other using Duncan's Multiple Range Test.

6. 3 Elucidation of Modes of Action (Enzyme Inhibition and Biomarker Responses) of Insect Pests

Madam Vice Chancellor, my research team explored the physiological and biochemical mechanisms underlying insect mortality, including enzyme inhibition and biomarker responses. Plant-derived compounds exert insecticidal effects not only through direct mortality but also by disrupting critical physiological and biochemical processes, especially the nervous system (Isman, 2020).

6.3.1. Response of some biomarker enzymes to terpinolene isolates as repellent against *Rhyzopertha dominica* infesting stored grains.

Oni, (2021) **:Oni** *et al*., (2022b) reported the repellent activity of terpinolene and its effects on antioxidant, neurotransmitter and detoxification enzymes in the larvae of *Rhyzopertha dominica* infesting wheat grains (Plate 27-28) by assaying the activities of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), acetylcholinesterase (AChE), carboxylesterase (CarEST) and glutathione S-transferase (GST). Dose 1.0 ml and the positive control produced 100 % repellency within 0–1 h, and was significantly higher than other treatments (Table 17). Terpinolene exerted stronger effects on superoxide-dismutase (SOD) and acetylcholinesterase (AChE) activities (Figs. 6 and 7), than on the other enzymes, suggesting that inhibition of these two enzymes may represent its primary mode of action. At higher dosages, catalase (CAT) and AChE activities were significantly reduced, whereas carboxylesterase CarEST, glutathione peroxidase GPx and glutathione S-transferase GST activities were significantly elevated. The enzymatic responses were dose-dependent, thus indicates that terpinolene possesses potent insecticidal properties and could be formulated to target superoxide-dismutase SOD and acetylcholinesterase AChE, which appear to be the key biochemical targets underlying its mode of action.

Plate 27: Infested wheat grain

Plate 28: Treated wheat grain

Table 17. Repellent activity of terpinolene against adult *R. dominica*

Treatment	Dosage (ml)	% Repellency (0–1 h)	% Repellency (1–4 h)	% Repellency (4–8 h)
Terpinolene	0.2	0.00 ± 0.00a	0.00 ± 0.00a	32.00 ± 5.83b
	0.4	0.00 ± 0.00a	24.00 ± 5.10b	42.00 ± 3.74b
	0.6	22.00 ± 4.90b	58.00 ± 8.60c	82.00 ± 9.70c
	0.8	60.00 ± 8.94c	86.00 ± 6.00d	100.00 ± 0.00d
	1.0	100.00 ± 0.00d	100.00 ± 0.00e	100.00 ± 0.00d
DDVP (positive control)	0.1	100.00 ± 0.00e	100.00 ± 0.00d	100.00 ± 0.00d
Negative control	0.0	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a

Each value is the mean of standard error of five replicates. Means followed by the same alphabet are not significantly different ($p>0.05$) using Tukey's Honestly Significant Difference (HSD) Test.

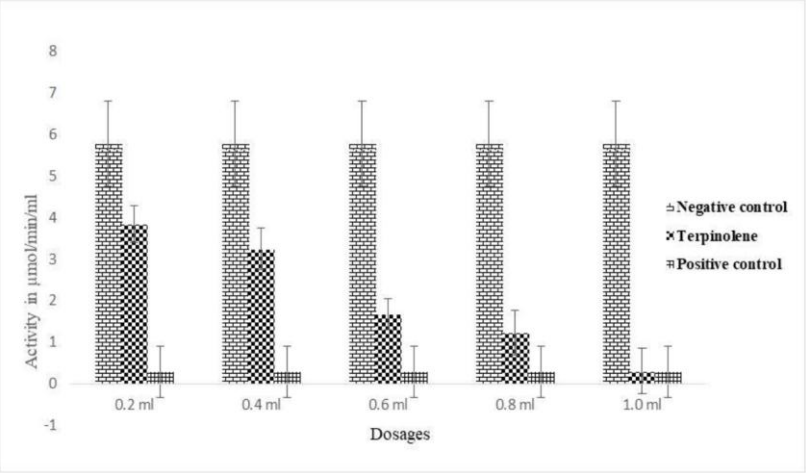

Fig. 6: Effect of terpinolene on the activity of SOD in *R. dominica* larvae

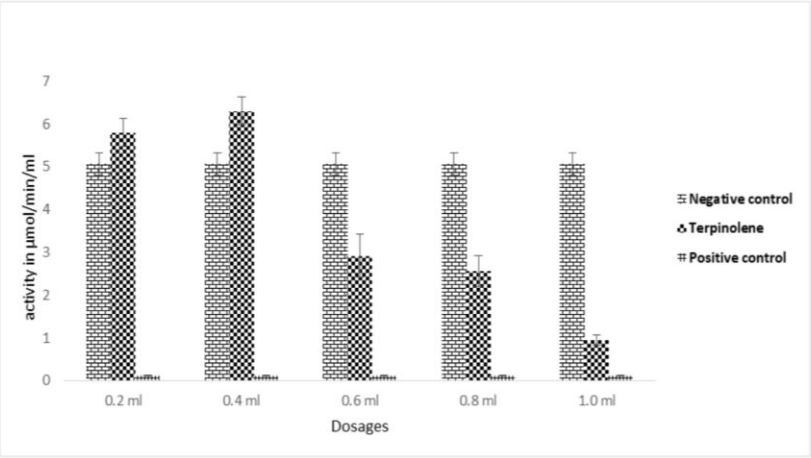

Fig. 7 Effect of terpinolene on AChE activity in *R. dominica* larvae

6.3.2 Anisaldehyde- Induced Mortality and Inhibition of Neurotransmitter Enzymes in Maize weevil

Madam Vice Chancellor, Adelakun, **Oni** and Adebayo, (2021d) reported the neurotoxic potential of anisaldehyde, an aromatic aldehyde evaluated as a candidate botanical insecticide on the maize weevil, *Sitophilus zeamais*. Probit regression analysis revealed that application of 50µl dosage of anisaldehyde resulted in 100% adult mortality at 96 h exposure, accompanied by complete inhibition of adult emergence thus indicating total suppression of progeny development (Tables 18 & 19). In addition to its lethal effects, anisaldehyde significantly interfered with key neurotransmitter and digestive enzyme systems. The activities of acetylcholinesterase (AChE) and carboxylesterase (CarEst) decreased progressively with increasing dosage with the control exhibiting the highest enzyme activities. At 50 µl, both enzymes were markedly inhibited, demonstrating a strong dose-dependent reduction in enzymatic function. This significant suppression of acetylcholinesterase AChE and carboxylesterase CarEst activities confirms the neurotoxic mode of action of anisaldehyde in *S. zeamais*, thereby supporting its potential as an effective botanically derived insecticidal agent.

Table 18. Anisaldehyde-induced effects on adult survival, emergence suppression and weight-loss in maize infested with Sitophilus zeamais

Treatment Adult (µl)	Mortality at 96hr	Adult emergence	% IR	% weight loss
10	60.00±5.77^{a}	15.33±1.20^{c}	65.15±2.73^{b}	2.12±.177^{a}
20	70.00±5.77^{b}	15.00±1.15^{bc}	65.91±2.62^{b}	1.73±0.27^{a}
30	93.33±3.33^{b}	7.00±1.15^{ab}	84.09±2.62^{c}	1.04±0.12^{a}
40	100.00±0.00^{c}	1.33±0.88^{a}	96.97±2.00^{d}	0.03±0.03^{a}
50	100.00±0.00^{c}	0.00±0.00^{a}	100.00±0.00^{d}	0.00±0.00^{a}
Control	3.33±3.33^{c}	37.33±3.53^{d}	0.00±0.00^{a}	32.15±1.50^{b}

Each value is the mean± standard error of three replicates. Values followed by the same alphabet are not significantly ($p>0.05$) different from each other using Tukey's Honestly Significant Difference Test.

Table 19. Dosage of anisaldehyde required to cause 50 and 95% mortality of *S. zeamais* within 72 h post-treatment

Slope ± S.E	Intercept ± S.E	χ^2	LD_{50} (95% FL)	LD_{95} (95% FL)	Sig.
2.80 ± 0.17	−0.12 ± 0.07	97.05	1.11 (0.73–1.41)	4.28 (3.28–12.00)	0.0001

Key: S.E = Standard error; χ^2 = Chi-square; LD = Lethal dosage; FL = Fiducial limit.

6.3.3 Insight into the toxicity of alpha- terpinene on protein content and lipid peroxidation of rice weevil Sitophilus oryzae

Afo, **Oni** and Adebayo (2022) evaluated the bioinsecticidal potential of α-terpinene against the rice weevil *S. oryzae* with emphasis on its effects on protein content, lipid peroxidation and key metabolic and detoxification enzymes including catalase (CAT), superoxide dimutase (SOD), glutathione peroxidase (AChE) and glutathione-S-transferase. Results showed that anisaldehyde and α-terpinene possess strong dose-dependent insecticidal and neurotoxic effects against major stored-product pests. Enzymatic assays revealed a progressive reduction in acetylcholinesterase (AChE) and carboxylesterase (CarEst) activities with increasing dosage, indicating severe disruption of neurotransmission and digestive processes. The marked suppression of these key enzymes confirms the neurotoxic mode of action of anisaldehyde and supports its potential as an effective botanically derived insecticide. Alpha-terpinene exhibited pronounced toxic effects on *S. oryzae* survival, with complete adult mortality recorded at 50 µl within 48 h, while lower doses produced partial but significant mortality in a clear dose–response pattern. The compound significantly altered the activities of antioxidant, detoxification and neurotransmitter enzymes, including CAT, SOD, GPx, AChE and glutathione transferase GST, leading to reduced protein content, increased lipid peroxidation and impaired metabolic function (Figs;8,9,10, 11&12). The biochemical disruptions explain the elevated mortality and confirm that α-terpinene exerts its insecticidal action through oxidative stress and enzyme inhibition, thus a promising plant-based bioinsecticide for stored-grain protection.

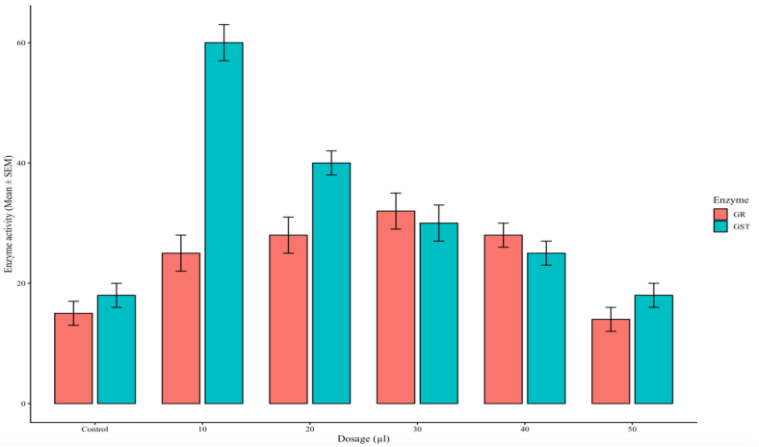

Fig. 8: Adult emergence of *S. oryzae*, seed weight loss and inhibition rate at different dosages of Alpha Terpinene. Bars represent mean ± SE.

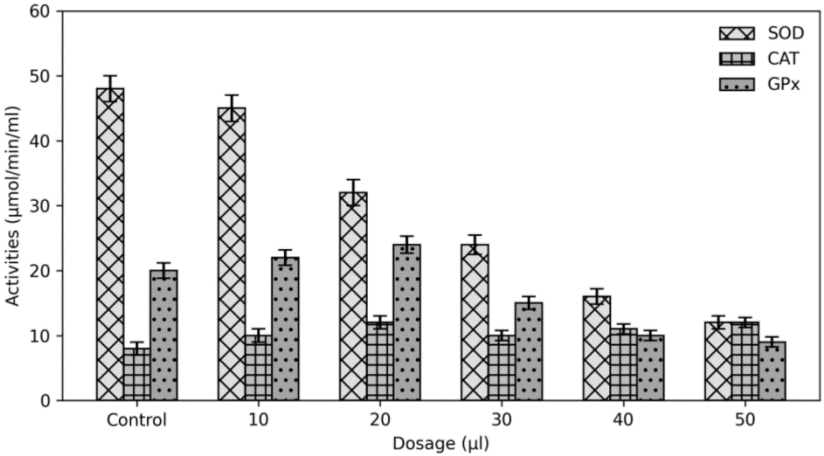

Fig. 9: Effect of Alpha terpinene on the antioxidant enzymes in adult *S. oryzae*

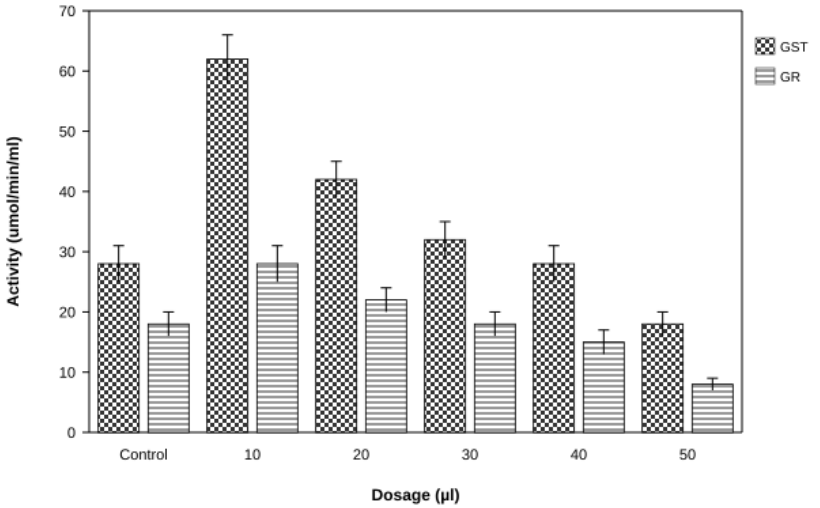

Fig 10: Effect of Alpha Terpinene on the glutathione transferase (GST), (GR) growth rate of adult *S. oryzae*

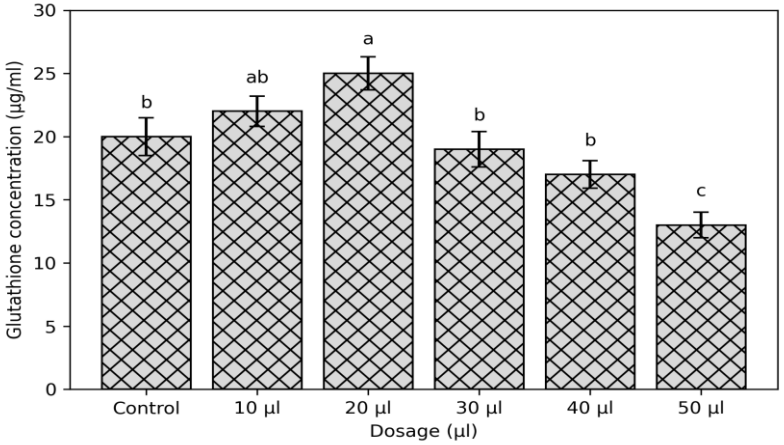

Fig 11: Effect of dosages of Alpha-terpinene on concentration of glutathione transferase (GSH). Bars represent mean ± SE. Bars with different letters are significantly different ($p < 0.05$).

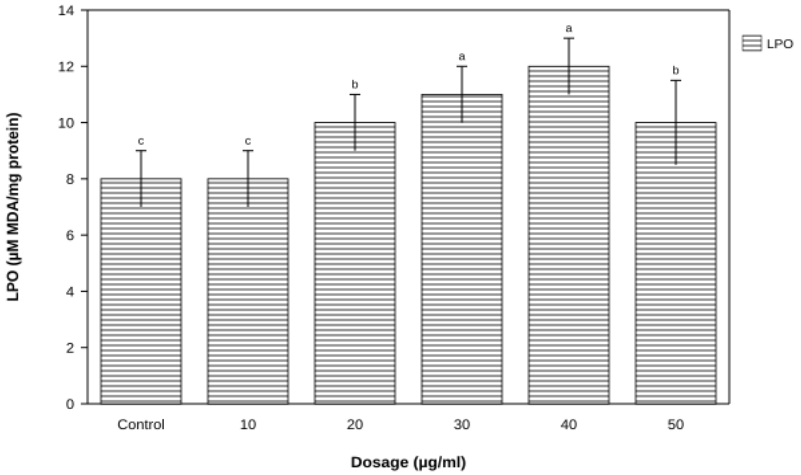

Fig. 12: Lipid peroxidation of adult *S. oryzae* treated with alpha terpinene

6.4. Isolation and Validation of specific Bioactive Compounds

Madam Vice Chancellor, in a quest to contribute our quota to identification, isolation, and validation of defined phytochemicals as bio-derived insecticides for grain protectants, my research group engaged into the screening of some botanicals found in Nigeria.

Oni *et al.*, (2021): Oni *et al*., (2022a), reported a significant ($p < 0.05$) direct toxicity of terpinolene compound on *Rhizopertha dominica* adult survival on wheat grains in both contact and fumigant toxicity tests with effectiveness improving as dosage increased Table 20. Higher dosages greatly reduced adult emergence, percentage inhibition, and seed weight loss compared

to the control. Terpinolene fumes showed strong toxicity against *Rhizopertha dominica* at 24 h, with LD_{50} of 3.75 and LD_{90} of 16.18. The moderate slope (2.59± 0.13) indicates a gradual increase in mortality with increasing dosage Table 21. The highly significant value (p= 0.0001) and narrow fiducial limits confirm the reliability of the probit model and effectiveness of the treatment.

Similarly, **Oni** and Oni (2022) reported the mode of action of anisaldehyde using neurotransmitter and digestive enzymes. It was observed that 50 µl dosage was more promising for the activity of acetylcholinesterase and was totally inhibited while a significant difference ($p<0.05$) exists between the activity of lipase and other digestive enzymes and neurotransmitters. (Figs. 13 and 14).

Table 20. *R. dominica* adult survival, emergence, percentage inhibition and seed weight loss by contact toxicity test

Treatment	Dosage (ml)	% mortality at 96h (Table 1)	Adult emergence	% IR	% weight loss
Terpinolene	0.2	70.00±3.16b	42.00±1.64e	38.60±2.40b	15.36±0.42e
Terpinolene	0.4	82.00±3.74bcd	35.20±0.92e	48.54±1.34c	11.08±0.98d
Terpinolene	0.6	94.00±4.00de	27.40±2.18cd	59.94±3.19d	7.21±0.58c
Terpinolene	0.8	100.00±0.00e	14.20±1.50b	79.24±2.19e	4.91±0.70bc
Terpinolene	1.0	100.00±0.00e	5.80±1.16a	91.52±1.69f	2.67±1.04ab
DDVP	0.1	100.00±0.00e	0.00±0.00a	100.00±0.00f	0.00±0.00a
Negative control	0.0	14.00±2.45a	68.00±2.65f	0.00±0.00a	41.70±1.23f

Each value is the mean ± standard error of five replicates. Mean followed by same alphabet are not significantly difference ($p>0.05$) Tukey's Honest Significant Difference

Table 21. Lethal dosage of terpinolene fumes against *Rhyzopertha dominica* at 24 h post-treatment

Treatment	Slope ± SE	Intercept ± SE	χ^2	LD_{50} (95% FL)	LD_{95} (95% FL)	Significance
Terpinolene	2.59 ± 0.13	−1.49 ± 0.07	135.30	3.75 (3.31–4.39)	16.18 (11.33–28.93)	0.0001

χ^2 = Chi-square; SE = Standard error; FL = Fiducial limits; LD = Lethal dosage.

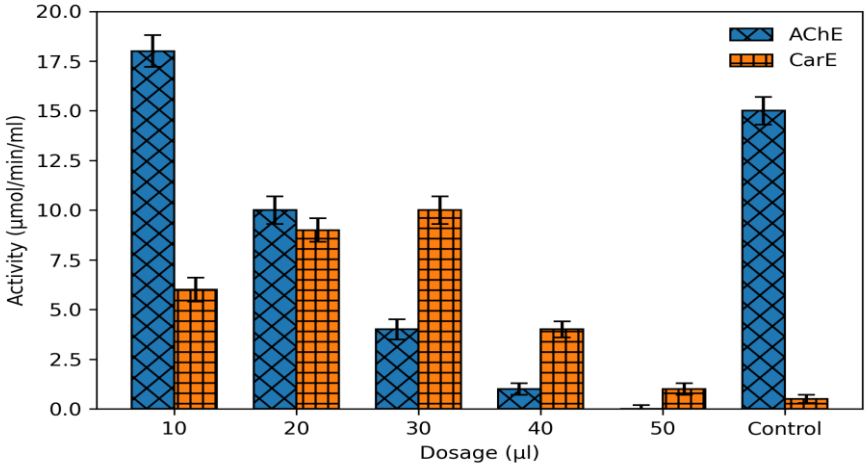

Fig. 13: Effect of different anisaldehyde on neurotransmitter enzymes on *R. dominica*

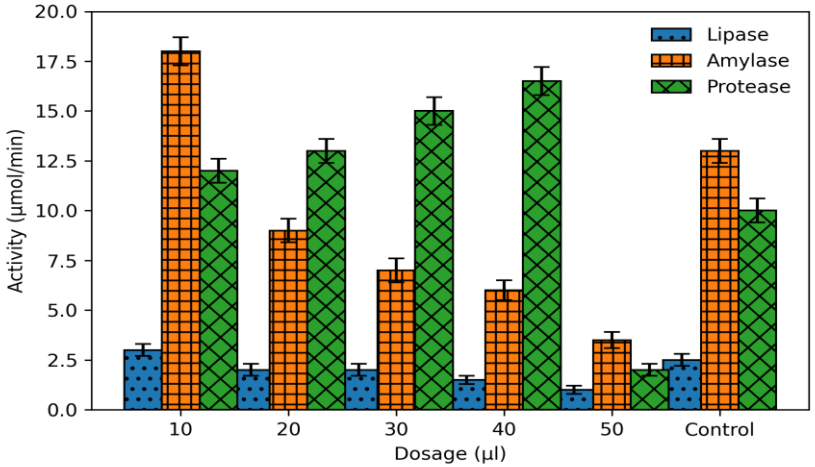

Fig. 14: Effect of anisaldehyde on the activities of digestive enzymes in *R. dominica*

6.5. Efficacy and Toxicological Evaluation of Botanical Insecticides against Major Grain Insect Pests

Madam Vice Chancellor, for over a decade, members of my research group have engaged in research to highlight the efficacy and toxicology of plant-derived insecticides against major storage and structural pests of cereals with emphasis on maize weeviI (*Sitophilus zeamais*) and Coleopterous species.

An investigation by IIeke and **Oni** (2011) on the toxicity of some plant powders to maize weevil *S. zeamais* on stored wheat grains revealed that *Azadiracta indica* and *Alstonia boonei* provide the maximum protection of the treated grains (Table 22). At three months storage, seed viability were not adversely affected, suggesting that seeds treated with *A. indica*, *A. boonei*, *Garcinia kola* and *Moringa oleifera* are suitable for consumption and planting stock and seed powders of *A. boonei* and *A. indica* . Collectively, this confirms that plant-based protectants can provide effective, environment -friendly pest control in stored cereals (**Oni** and IIeke, 2008; **Oni** *et al*., 2010b; **Oni,** 2011; **Oni,** 2014b).

Table 22. Effect of plant powders on number of *Sitophilus zeamais* adult emergence, percentage wheat grain weight loss, damage and seed viability after three months of storage.

Plant powders	Conc. w/w	Adult emergence after 42 days	% Weight loss	% Grain damaged	% Seed viability
Azadirachta indica	2.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	89.3 ± 0.6^{a}
	5.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	92.7 ± 0.7^{a}
	12.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	92.7 ± 0.7^{a}
	25.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	93.3 ± 0.6^{a}
Alstonia boonei	2.5	0.0 ± 0.0^{a}	0.8 ± 0.1^{a}	0.0 ± 0.0^{a}	90.0 ± 0.0^{a}
	5.0	0.0 ± 0.0^{a}	0.1 ± 0.0^{a}	0.0 ± 0.0^{a}	90.0 ± 0.0^{a}
	12.5	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	90.0 ± 0.0^{a}
	25.0	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	90.0 ± 0.0^{a}

Plant powders	Conc. w/w	Adult emergence after 42 days	% Weight loss	% Grain damaged	% Seed viability
Garcinia kola	2.5	3.3 ± 0.6^{a}	10.4 ± 0.2^{b}	0.9 ± 0.3^{a}	90.0 ± 0.0^{a}
	5.0	2.0 ± 0.0^{a}	6.3 ± 0.2^{ab}	0.5 ± 0.5^{a}	100.0 ± 0.0^{a}
	12.5	1.4 ± 0.2^{a}	3.9 ± 0.4^{a}	0.4 ± 0.1^{a}	93.3 ± 0.6^{a}
	25.0	0.0 ± 0.0^{a}	0.3 ± 0.6^{a}	0.0 ± 0.0^{a}	100.0 ± 0.0^{a}
Moringa oleifera	2.5	35.7 ± 0.5^{c}	22.9 ± 0.4^{c}	5.3 ± 0.8^{b}	89.3 ± 0.6^{a}
	5.0	31.3 ± 0.8^{bc}	17.7 ± 0.3^{bc}	3.0 ± 0.1^{ab}	90.0 ± 0.0^{a}
	12.5	27.0 ± 0.7^{b}	14.2 ± 0.4^{ab}	1.7 ± 0.3^{a}	93.3 ± 0.6^{a}
	25.0	15.7 ± 0.2^{a}	9.3 ± 1.2^{a}	0.0 ± 0.0^{a}	93.3 ± 0.6^{a}
Control (untreated)	0.0	64.1 ± 0.8^{d}	39.3 ± 0.2^{d}	22.7 ± 0.3^{d}	100.0 ± 0.0^{a}

Each value is the mean of ± standard error of three replicates. Mean followed by the same letter in a column are not significantly different ($P>0.05$) from each other using Duncan's new multiple range test.

Oni *et al*., (2019a) reported insecticidal effects of *Acalypha godseffiana* extracts on immature stages of adult *Rhizopertha dominica* and hepatoxicology of the extract at 2.88ml on albino rats and our findings revealed that 1.0ml dosage was effective while the leaf extract of *A. godseffiana* showed no adverse effect on mammal health especially at low dosage (Table 23).Total protein TP , Albumin and Globulin, Aspartate Aminotransferase AST and Alanine Aminotransferase ALT concentration in the blood serum, kidney and liver of sampled rats were also dosage dependent. Increase in extract dosage resulted in an increase in AST and ALT concentration in the blood serum of the rats, while total protein, albumin and globulin decreases at lower extract dosages.

Table 23. Effect of different dosage of 2.88% concentration of *A. godseffiana* oil extract on total protein (TP), albumin, globulin, ALT and AST of albino rats

Treatment (ml)	Tissue	Total protein (mg/dl)	Albumin (mg/dl)	Globulin (mg/dl)	ALT (U/L)	AST (U/L)
0.2	Blood serum	3.98 ± 1.28cd	2.12 ± 4.27c	1.86 ± 2.56a	2.57 ± 5.34a	2.84 ± 2.18a
	Kidney	2.27 ± 0.36b	1.45 ± 1.72bc	0.82 ± 0.96a	1.34 ± 2.76a	1.13 ± 3.91a
	Liver	2.13 ± 1.73b	1.18 ± 3.05b	0.95 ± 0.86a	1.18 ± 2.43a	1.00 ± 0.56a
0.6	Blood serum	3.44 ± 0.79c	1.74 ± 6.14	1.70 ± 2.51a	4.74 ± 3.19b	5.05 ± 4.33b
	Kidney	1.52 ± 1.62ab	0.86 ± 0.58ab	0.66 ± 3.23a	2.34 ± 2.63a	1.78 ± 1.57a
	Liver	1.25 ± 0.67ab	0.72 ± 3.77ab	0.53 ± 0.79a	0.96 ± 7.76a	0.84 ± 1.00a

Treatment (ml)	Tissue	Total protein (mg/dl)	Albumin (mg/dl)	Globulin (mg/dl)	ALT (U/L)	AST (U/L)
1.0	Blood serum	2.68 ± 2.64	1.10 ± 2.59b	1.58 ± 7.23a	7.45 ± 2.51c	8.59 ± 2.64c
	Kidney	0.79 ± 3.62a	0.42 ± 3.54a	0.37 ± 1.45a	2.54 ± 1.87a	1.83 ± 1.70a
	Liver	0.64 ± 2.58a	0.37 ± 5.74a	0.27 ± 0.69a	0.72 ± 4.10a	0.54 ± 0.45a
Control	Blood serum	3.99 ± 1.54cd	2.15 ± 3.13c	1.84 ± 1.42a	2.56 ± 4.23a	2.84 ± 2.21a
	Kidney	2.30 ± 0.82bc	1.51 ± 1.75b	0.79 ± 1.77a	1.32 ± 2.17a	1.15 ± 1.67a
	Liver	2.15 ± 1.68b	1.16 ± 3.59b	0.99 ± 0.52a	1.18 ± 1.94a	1.02 ± 0.69a

Each value is the mean ± standard error of six replicates. Values with the same alphabet in the same column were not significantly different ($p > 0.05$) from each other using Tukey post hoc test.

In another study, **Oni** *et al*., (2019b): **Oni** (2019c) reported the inhibitory effects of oil extract of *Acalypha wilkesiana* leaves on antioxidant, neurotransmitter and detoxifying enzyme in adult *C. maculatus* exposed to varying dosages of the homogenized extracts. The supernatants obtained were used as enzyme sources, similar to earlier reports that activities of the enzymes increased at low dosages of the oil 0.6, 0.8 and 1.0 ml respectively and acetylcholesterase AChE activity was inhibited by the oil extracts, Fig. 15.

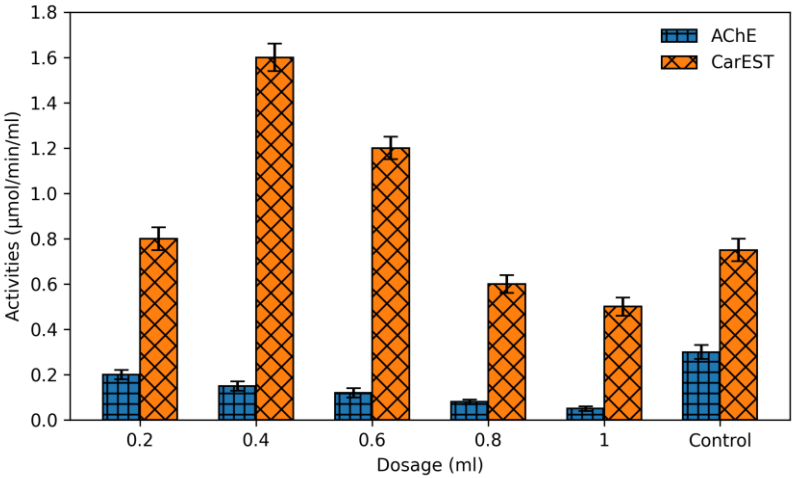

Fig. 15: Effect of oil extract of *A. wilkesiana* on the activities of AchE and CarEST in adult *C. maculatus*.

Oni *et al*., (2022b) confirmed the insecticidal and toxicological effects of *Dennettia tripetala* fruit oil extract as stored cowpea protectants against *Callosobruchus maculatus* and noted that 1.0 ml dosage was the most effective as it evoked 100% beetle mortality within 24 h ($p<0.05$) and its effectiveness was dosage dependent (**Oni** *et al*.,2022b). All dosages displayed significant lethal effects on the insect as compared with the untreated check. Treated seeds with the highest dose of 1.0 ml *D. tripetala* extract

inhibit immature stages and hence reduced infestation and subsequent damage of treated seeds. Liver and kidney function bioassays involving the use of rat and different levels of *D.* tripetala showed that the bilirubin, glutamyl transferase GGT and Uric acid were high as the dosages increased while total protein was at its least (0.06g/dl) when compared to other groups (Table 24). The low values of AST (Aspartate Aminotransferase), ALP (Alkaline Phosphate), ALT (Alanine Aminotransferase) and Creatine concentrations recorded at 1.0ml of 2% concentration of *D. tripetala* oil extract has no hepatotoxic effect on animals (Table 25). Thus, *Dennettia tripetala* extract could be a potential toxicant and of great importance in storage protection of stored cowpea against the bruchids.

Table 24. Effect of oil extract of *D. tripetala* on some biochemical parameters of albino rats

Dosages (ml)	Bilirubin	Total protein	GGT	Uric acid
1	23.42±2.37a	1.44±.285b	16.98±1.57a	11.40±0.33a
3	36.02±2.76b	1.05±0.03b	21.84±0.69ab	20.13±0.97b
5	38.03±2.19b	1.06±0.020b	27.42±1.64b	25.56±2.03c
C1	21.75±2.3a	1.15±0.013b	18.00±1.44a	10.58±0.32a
C2	69.11±1.12c	0.06±0.02a	38.02±1.31c	50.25±1.14d

Each value is the mean ± standard error of six replicates. Values followed by the same letter in the same column are not significantly ($p>0.05$) different from each other using the Tukey Honestly Significant Test.

Legend: GGT *(GlutamylTransferase)*

Table 25. Effect of different dosages of 2 % concentration of *D. tripetala* oil extract on AST, ALP, ALT and creatinine of albino rats

Dosage	AST (U/L)	ALP (U/L)	ALT (U/L)	Creatinine (mg/dL)
1	16.32 ± 2.07^{a}	53.18 ± 1.06^{ab}	40.68 ± 2.09^{a}	2.81 ± 0.96^{a}
3	24.66 ± 2.07^{a}	51.24 ± 5.49^{ab}	44.82 ± 2.30^{a}	5.89 ± 0.96^{a}
5	26.17 ± 1.65^{a}	58.13 ± 4.22^{b}	54.84 ± 2.12^{b}	15.19 ± 0.75^{b}
C1	23.72 ± 2.66^{a}	34.61 ± 5.79^{a}	40.19 ± 2.46^{a}	2.26 ± 0.61^{a}
C2	87.53 ± 2.96^{b}	86.49 ± 3.18^{c}	91.79 ± 0.52^{c}	23.78 ± 2.99^{c}

Each value is the mean ± standard error of six replicates. Values followed by the same letter in the same column and not significantly ($p>0.05$) different from each other using Tukey Honestly Significant Test.

Legend: AST *(Aspariate Aminotransferase),* ALP *(Alkaline Phosphate),* ALT *(Alanine Aminotransferase)*

C1 (Negative control)

C2 (Positive control).

Similarly, **Oni** *et al.* (2019a) reported the insecticidal and hepatotoxicity effects of *Acalypha godseffiana* extracts 0.2, 0.4, 0.6, 0.8 1.0ml on adult *Rhyzopertha dominica* and at 2.88 ml on albino rats. Only 1.0 ml dosage of the extract achieved up to 98% mortality of the insect between 96 h and the emergence of the insects and percentage inhibition rate and the ability of the insect to cause weight loss of grains were dosage dependent. The active compound present in the extract was analyzed using Gas Chromatograph Mass Spectrometry (GC-MS), Bicyclo[3.1.1] heptane, 2,6,6-trimethyl (1.alpha.,2.beta..5.alpha.) were abundant in the extract (Table 26). Total protein, Albumin and Globulin, AST and ALT concentration in the blood serum, kidney and liver were dose dependent. Increase in the dosage of the extract resulted in an increase in AST and ALT concentration in the blood serum of the rats while there was decrease in the total protein, albumin and globulin at lower dosages.

A. godseffiana extract has shown high insecticidal potential and little or no mammalian toxicity.

Table 26. Chemical composition of crude oil extracts of *A. godseffiana*

Peak no.	Compound	RI (cal.)	% Composition	Identification method
1	Benzene, 1-methyl-3-(1-methylethyl)	218	1.39	MS, RI
2	Tetradecane	1048	1.92	MS, RI
3	Caryophyllene	1099	25.00	MS, RI
4	Hexadecane	1456	3.58	MS, RI, Co
5	Benzoic acid, 2,4-bis[(trimethylsilyl)oxy]-, trimethylsilyl ester	1554	3.81	MS, RI
6	Octadecane	1759	6.49	MS, RI
7	Cyclotetradecane	1776	1.13	MS, RI
8	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl (1α,2β,5α)	1809	38.74	MS, RI
9	1,2-Benzenedicarboxylic acid, dipropyl ester	2042	2.57	MS, RI, Co
10	Eicosane	2073	3.69	MS, RI, Co
11	Cyclodecane, octyl	2091	0.71	MS, RI
12	1-Docosene	2378	1.26	MS, RI, Co
13	1-[p-Bromophenyl]-4-nitro-1,3-butadiene	2912	7.68	MS, RI
14	Squalene	4043	2.05	MS, RI, Co

Retention Index (RI) relative to the homologous series of *n*-hydrocarbons on the HP-5 MS capillary column. Relative values are peak areas relative to the total peak area.

7.0 CONCLUSION

Madam Vice-Chancellor, distinguish ladies and gentlemen; in a nutshell I have presented my major contributions to knowledge in the field of Stored Product Entomology. I have demonstrated through my research findings comprehensive scholarly contributions to the development and application of plant-derived insecticides as an eco-friendly and scientifically validated tool for the control of stored-product pests. Drawing on extensive experimental research, this lecture documents advances in efficacy and validation of botanicals, their formulation development, fumigant and contact toxicity evaluation, and the elucidation of biochemical and enzymatic modes of action. The influence of environmental and biological modifiers on pest responses, which strengthens the understanding of variability in insect susceptibility under storage conditions was examined in this lecture.

Through systematic laboratory bioassays involving solvent extraction studies, fumigant evaluations, and enzyme-based toxicological analyses, we have been able to show that botanical insecticides can achieve high levels of efficacy that is comparable to those of conventional synthetic chemicals, while offering superior environmental compatibility and safety. The lecture therefore synthesizes research on the efficacy, formulation, biochemical mechanisms of action, and practical integration of plant-derived insecticides into stored-product pest management systems, establishing them as sustainable alternatives for stored product protection.

8.0. RECOMMENDATIONS

1. Government and agricultural development agencies should promote the use of locally sourced botanicals to enhance accessibility, adoption and long term sustainability. The government should strengthen farmers' training and extension outreach on plant-derived insecticide use by providing financial support for these activities and enable farmers active participation to enhance knowledge, proper usage and adoption of these plant-derived insecticides.
2. Researchers should optimize dosages and application methods for specific pests and storage environments. Agricultural extension agencies should translate these findings into guidelines and training materials to farmers.
3. Government, policy makers and agricultural agencies should integrate plant-derived insecticides into comprehensive Integrated Pest Management (IPM) programmes.
4. Researchers and formulation scientists should develop improved formulations with enhanced stability and residual effects.
5. The government should create enabling policies, incentives, encourage policy support and private-sector participation in commercialization. Collaborating with private sector companies and entrepreneurs will improve availability, affordability and long-term sustainability of plant-derived insecticides.
6. Government and academic institutions should support interdisciplinary collaboration among entomologists, toxicologists such integrated research will improve

understanding of efficacy, farmer-adoption, economic viability, and policy implications of plant-derived insecticides.

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