FEDERAL UNIVERSITY OF LAFIA

INAUGURAL LECTURE SERIES NO. 12

FACULTY OF AGRICULTURE

INSECTS:
DIVERSITY, NATURAL AND STRATEGIC WAR

MONDAY U. UKWELA
Professor of Crop Entomology
Department of Agronomy

March 12, 2024

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NATIONAL LIBRARY OF NIGERIA CATALOGUING-IN-PUBLICATION DATA

Insects: Diversity, Natural and strategic War / by Ukwela, U. Monday
1. Insects, Pests-Research

i. FULAFIA Faculty of Agriculture Inaugural Lecture Series
ii. Title
SB 933.14 U 34 2023 632.7

ISBN: 978- 978-784-105-1

ISSN: 3027-2807

Publisher:
FULAFIA PRESS,
Federal University of Lafia,
P.M.B 146, Lafia,
Nasarawa State,
Nigeria.

Print @
Castle Mart Hubs,
No. 2, Abonnama Close,
Off Emeka Anyaoku Street,
Area 11, Garki Abuja.
08033147706

Dedication

This work is dedicated to God Almighty, my creator who has been my strength.

THE PRESENTER

MONDAY U. UKWELA

Professor of Crop Entomology

Department of Agronomy

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Table of Contents

1.0 PREAMBLE

The Vice-Chancellor, Deputy Vice-Chancellor Administration, Deputy Vice-Chancellor Academic, Deputy Vice-Chancellor Research and Partnership the University Registrar, the Bursar and the Liberian of this great University, Provost of the College of Medicine, Dean of the Postgraduate School, My own Dean, Faculty of Agriculture, other Deans of other Faculties, Dean of student Affairs, Directors here present, other members of the University Senate, my own Head of Department, members of the press here present, the Great students of FULAFIA, members of the congregation, Ladies and Gentlemen.

With great sense of humility and gratitude to Almighty God, I appear before YOU today to deliver the 12th Inaugural Lecture of this Federal University of Lafia. I feel delighted and honored to give my lecture as a Professor of Crop Entomology. It is the first Inaugural Lecture of the Department of Agronomy and Faculty of Agriculture of the Federal University of Lafia. Indeed, I consider it a great privilege to stand before you to present this Lecture titled "Insects: Diversity, Natural and Strategic War". Mr. Vice-Chancellor, Sir, I was determined to deliver this Lecture in the Federal University of Agriculture, Makurdi (FUAM) now named, Joseph Sarwuan Tarka University, Makurdi (JOSTUM) before my migration to this great Federal University, but due to one or two major challenges I could not do the lecture until now even though I became a Professor as far back as First October, 2010.

Mr. Vice-Chancellor Sir, my own Father, Mr. Josiah I. Ukwela of blessed memory, was a prominent Local farmer at Unale in Ibaji L.G.A, Kogi State. Through farming, he trained his seven (7) sons to become University graduates among whom I am number three (3). During my intermediate school, I had a burden to study Agriculture during my University education. This was because I sincerely desired to be of help to my people especially in the area of crop protection. Most of the people in my Local Government Area are farmers till today and they are deficient when it comes to protection of their crop from the pests and diseases. Studying Agriculture gave me much opportunities to be of great help to farmers as well as both undergraduate and postgraduate students whom I mentored through teaching and research.

Mr Vice-Chancellor Sir, the Holy Book of God clearly told us to consider the wisdom of ants which provide their meat in summer and gather their food at harvest (Prov. 6:6-8). Wisdom is effective application of knowledge. In a well conducted research, you are bound to acquire a sound knowledge for management of the pest population in its immediate ecology. In order to effectively manage insect pest populations, good knowledge of reproductive and developmental biology of insects on their host plants are very much required.

Based on my research interest, I was first to study the biology and damage potential of an insect commonly called Shield Bug, *Aspavia armigera* F. (Hemiptera: Pentatomidae) on Cowpea crop. This shield bug was first reported by Golding (1946) on cowpea and rice crops, and I was the first to study on this bug during late season of 1984. The research established the colossal damage to economic threshold in Nigeria. My next research work on the Hemipterans was the study on the biology and population assessment of a Coreid bug, *Cletus fuscescens* (walk) (Hemiptera: Coreidae) on *Amaranthus* lines. In that study, I discovered that more than 50% of Amaranthus grains are lost to the bug. My advanced studies dwelled more on an exotic mango mealybug pest whose activities troubled many West African countries beginning from Republic of Togo and Ghana as far back as 1981 to 1982 but was first found in Nigeria late 1987.

2.0. INTRODUCTION

2.1. ENTOMOLOGY:

Is the study of insect and closely related organisms. This study includes their life cycles, types, forms, activities and how to control or eradicate the harmful ones (pests) or protect the more beneficial ones.

What are Insects?

Insects are small-sized hexapod invertebrates usually recognized by possession of well defined three body regions namely, the head, thorax and the abdomen. They also have six jointed appendages, one or two pairs of wings, a pair of antennae, exoskeleton and a pair of compound eyes to mention a few. In several cases, insects live with us. Insects constitute about 75% of all described animal species and are well adapted to virtually all ecological habitats. These attributes coupled with their high reproductive potential, small size and ability to feed on a wide variety of food stuffs accounted for the success of this class of animal. Insects colonized this earth for at least 300 million years before the advent of man (Adedire, 2011).

Insects belong to a large group of lower animals called Arthropods. Insects belong to class Insecta (or Hexapoda) and consist of several orders, families, genera and species based on their diverse nature. Insect is the largest group among the animal kingdom. They are found in temperate, cold, warm, sub-tropical and tropical regions of the world.

Insects may be classified into two groups including Apterigota (wingless insects) and Pterigota (winged insects). Apterigota comprise of small ancestral wingless insects with simple metamorphosis with the presence of the style-like appendages on pre-genital abdominal segments. They are characterized with continuous moulting throughout their life and this group includes orders Protura, Thysanura and Diplura.

Pterigota are winged insects. The wings could be lost with time. The group is divided into Exopterigota and Endopterigota. Several orders of insect are also found under each group.

Insects are also classified based on their life cycles or development. Metamorphosis is the series of changes through which an insect undergoes beginning from egg through larva, pupal to adult (or imago). The larval stages of Endopterigota are referred to as larva while those of Exopterigota are known as nymph. On the basis of the degree of metamorphosis insects are grouped into three (3) main types including

(a) Ametabolous where development in an insect is with very little change and metamorphosis is absent;
(b) Hemi-metabolous (incomplete metamorphosis); and
(c) Holometabolous (complete metamorphosis

2.2. SUCCESS IN INSECTS

- Presence of exoskeleton which is extremely hard outercutin. Consequently insects have water conservation mechanism.
- A very high fecundity coupled with very short life span or life cycle especially in the tropics resulting in very large increase in number. eg a queen termite lays about 60 eggs per minute and will continue to lay eggs for 17 years.
- The small size of most insects enable individuals to find sufficient food to complete their life cycle even during serious adversity. Note that insects compensate for their small size by their large numbers.
- Small insects have been dispersed with sexual reproduction and can produce their young parthogenetically, especially during the period of colonization and rapid increase in number.

2.3. INSECT'S HARM TO MAN

- They compete with man for the insufficient organic food available to the world's living population.
- They compete with man for living space e.g. lice, Jigger, bed bugs, ticks on domestic animals, etc.
- Vectors of deadly diseases of man e.g. mosquitoes, horseflies, houseflies, etc.
- Attack animals or livestock and crops and even man's properties like puncturing books and clothes.
- They cause damage and series of losses to our stored food products and the damage may begin from field-to-store in several cases e.g. maize weevils (*Sitophilus zeamais*), Cowpea

seed Bruchid (*Callosobrucus maculatus*), Red flour beetle(*Tribolium castaneum*).

2.4. REASONS FOR INSECT DIVERSITY

- They exhibit high rate of reproduction involving sexual form, parthenogenetic form, viviparity, oviparity, ovoviviparity forms of reproduction.
- Insects exhibit high adaptive ability in both cold and warm regions.
- Insects have two major types of mouth parts including mandibulate and Haustellate. The mouth part could be modified for chewing and biting, gnawing, chewing and sucking, siphoning, piercing and sucking types.
- Insects have modified legs especially for swimming, grasping, digging, running and jumping
- Insects possess wings that may be absent with time or present throughout their life time for flying from one place to another in an effort to escape from their enemies.
- Insects have different developmental stages, some stages live in water (egg and larvae) and some live on land (e.g. Adults). Dragon fly (e.g. eggs and larva) and adult live on land. The same thing goes for mosquitoes whose adults live on land while the eggs, larvae and pupae live in water.

2.5. CLASSIFICATION BASED ON MOUTH PARTS

The type of damage an insect does is dependent on the type of mouth part it has. Broadly speaking the two types of mouth part in insects include (a) Mandibulate and (b) Haustellate

(a) Mandibulate (i.e. biting and chewing). Insects with this type of mouth part are called primitive ones and this type is found in the larval forms of all insects except in the order Hemiptera. This type of mouth part is found in members of orders: Collembolla, Orthoptera, Odonata and Coleopteran. Mandibles in the mouth part are used for cutting and chewing of their food. Here, the mouth part consist of the following; the labrum, which is a broad-like structure found below the clypeus. This is capable of movement forward and backward and does assist the mandible during feeding. Mandibulate mouth parts could be modified into: chewing and sucking type as found in honey bees and some larval forms of insect. In this case the insects obtain their food in liquid forms by sucking it through the sternum in its mouth. In bees the labium and maxillae are modified into tongue-like structure into which the food passes.

(b) Haustellate: in the haustellate type of mouth parts some or all the various parts are modified into elongated or spear-like structure for sucking food. This is rather a segment beak. The beak arises from the front or hind part of head and extends backward along the ventral surface sometimes as far back as the base of the leg. The segment portion of the beak is a region. The pairs of mandibles and maxillae are modified into mandibular stylet and maxillary stylet. The modified labium serves as a sheet for these stylets. Most pairs of stylet therefore form hollow-like setae for piercing and sucking, and these have limited extension. There are no palps in the Haustellate mouth. The labrum is a form of a flap covering the labium from the base.

2.6. BENEFITS OF INSECTS TO MAN

Bio-control of insect pests

(a) The knowledge of predaceous and parasitic insect species (e.g. parasitoids) help in the regulation of population levels of many insect pests in nature. Scientists have used entomophagous insects to control successfully the exotic insect pests. Predators such as ladybird beetle, dragon fly have been used. Endoparasitic parasitoids *Epidinocarsis lopezi* (De Santis) was used in the control of the cassava mealy bug *Phenacoccus manihoti* (Malt-Ferr) and the mango mealy bug (*Rastrococcus invadens* (Williams)) was controlled by use of another exotic Endoparasitic parasitoid known as *Gyranusioidea tebygi* (Noyes) in West Africa by scientists.

The two mentioned parasitoids belong to Family Encyrtidae and order Hymenoptera; other important families in bio control include Braconidae, Ichneumonidae and Technidae.

(b) Insects such as winged termites, soldier termites, larvae of many beetles and some caterpillars, yam beetles, wild crickets are used as food and do supplement the much protein diet.

(c) Natural products of insects such as bee wax, honey shellac are important items of commerce. Cochinceal is a red dye obtained from the bodies of mealy bug called *Dactilopius coccus*, and it is put into various uses in dyeing industries. The cocoon spinned by the larvae of *Bombyx mori* and *Anaphe* spp. h ave become the source of valuable commercial fabrics, silk.

(d) In medicine: Bee venom has been used to treat Arthritis. An extract from a blister beetle Acantharidin has been used in treating certain urinogenital organ.

(e) Honey bee is presently used in domesticated forms purposely to pollinate agricultural crops. Adocile strains are held in hives and multiplied in apiaries both for honey and wax production and also for pollinating certain crops.

(f) Scavenging insects: They reconvert waste materials into simpler organic matter that increase the fertility of soil (e.g. dung beetle).

(g) Activities of insects have added much to scientific knowledge, for example, *Drosophila* spp. (fruit fly) has been extensively used in cytogenetic studies.

(h) In the development of insecticides insects have been used in bio-assay tests because of ease of rearing and handling under laboratory condition.

(i) A great variety of colour and shapes exhibited by insects provides artistic inclination, designers and artists imitate the patterns.

3.0. THE MAIN FOCUS OF THE INAUGURAL LECTURE;

3.1. SURVEY AND ECOLOGICAL ESTABLISHMENT OF *RASTROCOCUS. INVADENS*

The present survey has established the extent of spread and seasonal distribution of *R. invadens in the Guinea Savanna of Nigeria.* A nation-wide survey by Ivbijaro *et al.* (1992) only showed the presence of *R. invadens* in the Southern part of the Country. This finding shows that *R. invadens* has the ability to survive in different ecological zones since the Southern area is more humid for most part of the year compared to the drier conditions of the Northern Guinea Savanna of Nigeria (Table 1).

Table 1: Period and date of survey of host plant species of R. invadens at four different locations of Guinea Savanna

Period and date of survey		
Location	**Dry season**	**Rainy season**
Makurdi	21 - 28th December 1993	20 - 24th August 1994
Jos	26 - 28th March 1994	26 - 30th August 1994
Kaduna	21 - 25th March 1994	2 - 5th September 1994
Abuja	15 - 20th March 1994	6 - 8th September 1994

This ability of the mealybug to thrive well on its host plants in different ecological zones was reported in Republic of Togo (Agricola *et al.*, 1989) (Figure 1).

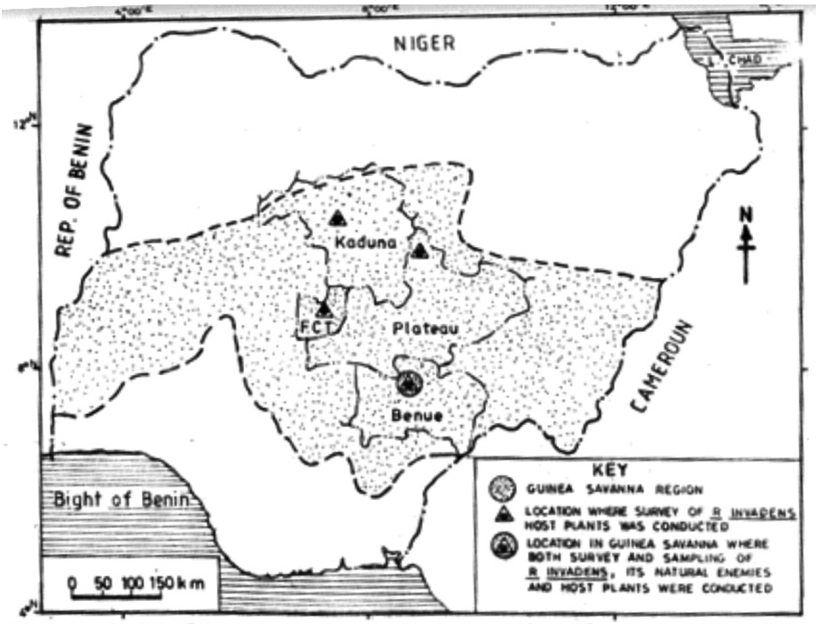


Figure 1 : Nigeria's Guinea Savanna zone showing locations of survey and sampling of Rastrococcus invadens Williams, its natural enemies and host plants

3.2. HOST PLANTS INFESTATION BY R. INVADENS

In general, percent infestation of host plants, the fruit tree crops, was higher during the dry season than in the rainy season. This finding agreed with the report of several authors (Agounke *et al.,* 1988; Agricola *et al.,* 1989) that the mealybug number increases during dry weather and drop during rains. This study also showed that *R. invadens* feed on several host plants which belong to different plant families. The thirty (30) host plant species from different parts of Guinea Savanna in the survey was higher than the twenty (20) identified in Southern Nigria (Ivbijaro *et al.,* 1992) and closer to the number recorded in Gabon (Boussienguet and Mouloungou, 1993) (Table 2).

Table 2: Host-plants of R. invadens identified during the dry and rainy-seasons survey and their percentage infestation in Guinea Savanna of Nigeria.

S/N	Family/Scientific Name	Common Name	*Location of sampled host plants	Av. % leaves infested		Av. % leaf infestation at both seasons
				DS	RS	
1.	Anacardiaceae					
	Mangifera indica	mango	MK, AB, KD	83.9	78.6	81.3
2.	Rutaceae					
	Citrus sinensis	sweet orange	AB, KD, MK	58.4	37.8	48.1
	Citrus paradisi	grape orange	MK	55.0	58.8	56.9
	Citrus aurentifolia	bitter orange	AB	52.5	46.0	49.3
3.	Myrtaceae					
	Psidium guajava	guava	MK, KD, AB	26.3	25.0	25.7
4.	Musaceae		MK, AB	56.0	26.7	41.4
	Musa sapientum	banana				
5.	Caricaceae					
	Carica papaya	pawpaw	KD	7.5	0.0	3.8
6.	Apocynaceae					
	Plumeria alba	frangipani	KD, MK	64.9	48.0	56.5
	Plumeria rubra	frangipani	KD, MK	50.2	34.3	42.3
	Plumeria sp(hybrid)	frangipani	MK	33.8	17.5	25.7
	Nerium oleander	oleander	MK, KD, AB	56.0	42.1	49.1
7.	Moraceae					
	Ficus ovata	shade tree	KD, MK	7.5	79.2	43.4
	Ficus vogelii	shade tree	KD	65.0	87.5	76.3
	Ficus umbellata	shade tree	AB, MK	55..0	23.8	39.4
	Ficus elastica	shade tree	MK	12.5	0.0	6.3
	Ficus varrifolia	shade tree	MK	0.0	75.0	37.5
	Ficus polita	shade tree	AB, KD, MK	46.3	35.6	41.0
	Ficus glumosa var glaberrima	shade tree	KD	0.0	88.8	44.4
	Ficus insigens	shade tree	AB	0.0	98.3	49.2
	Ficus vogeliana	shade tree	MK	52.0	39.2	45.6
8.	Araceae					
	Dieffenbacchia maculate		MK	26.2	38.3	32.3
	Culcasia sp.		AB, MK	20.0	20.0	20.0
	Colocasia esculenta	cocoyam	KD	0.0	65.0	32.5
9.	Acanthaceae					
	Jacabonia sp.		KD, AB	11.0	10.0	10.5
	Graptophyllum pictum		KD, MK	44.7	26.5	35.6
	Sanchezia nobilis		MK, AB	51.2	42.2	46.8
	Asystasia decipens		KD	17.5	24.6	21.1
10.	Euphorbiaceae	red acalifer	MK, KD, AB	14.4	24.8	19.6
	Acalypha sp.					
11.	Asclipiadaceae					
	Calotropis plocera		MK	15.0	0.0	7.5
12.	Agavaceae		AB	0.0	21.0	10.5
	Dracaena sp.					

*MK = Makurdi; AB = Abuja; KD = Kaduna; DS = Dry-season; RS = Rainy-season.

The authors also recorded mango, citrus, fig trees, frangipani and guava as preferred host plant species which are also confirmed in the present list of preferred host plants in Guinea Savanna. Mango reported to be the most important host plants of *R. invadens* by Several authors (Williams, 1986; Agounke *et al.,* 1988; Willink and Moore, 1988; Neuenschwander, 1989; Boavida *et al.,*1992) recorded the highest percent infestation compared to other host plants in this study. Fortuitous host *plants*, cashew (*Anarcadium occidentale*), neem (*Azadirachta indica*), maize (Zea *mays*), bush milk (*Theretia nerifolia*), pineapple (*Anana sativa*) and almond tree (*Terminalia* species) observed in Southern Nigeria (Ivbijaro *et al.,* 1992 and Akinlosotu *et al.,* 1992) were not infested throughout my survey. These host plants listed here were not among the preferred ones. Other fortuitous host plants, cocoyam (*Colocasia* sp.) and pawpaw (*Carica* papaya), found at the sites of heavily infested mango (*M. indica*) in this study, were among the ones identified by the previous authors. This inherent nature of *R. Invadens* to feed and survive on many host plants pose great difficulty to effectively control the insect. Such a wide host range serve as reservoirs for re-infestation of the major host plants.

3.3. IMPACTS OF ABIOTIC FACTORS ON MEALYBUG POPULATION

Figure 2 shows the map of Makurdi local government area with six (6) locations for sampling of mango mealybug.

51

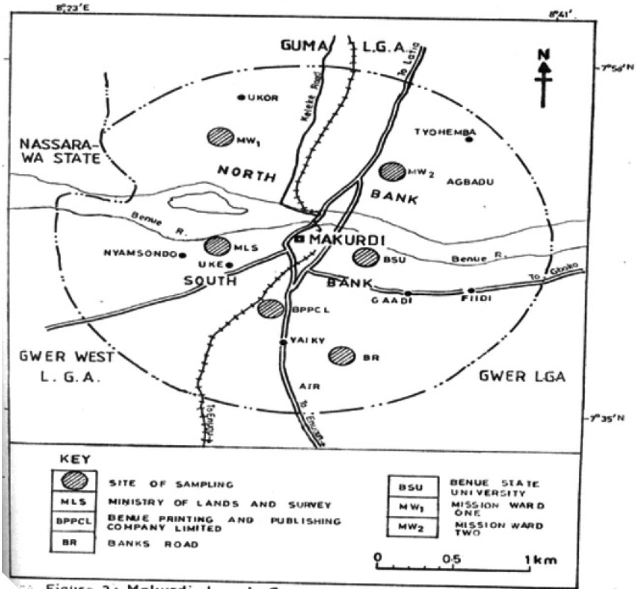


Figure 2: Makurdi Local Government Area showing sites of sampling of Rastrococcus invadens Williams and its natural enemies.

In this study, the impact of a few abiotic factors like wind, rainfall, relative humidity and temperature, on *R. invadens* population was observed at both dry and rainy seasons. Wind and rainfall were the most important factors that influenced the population density of *R. invadens* on mango during the period. (Figure 3).

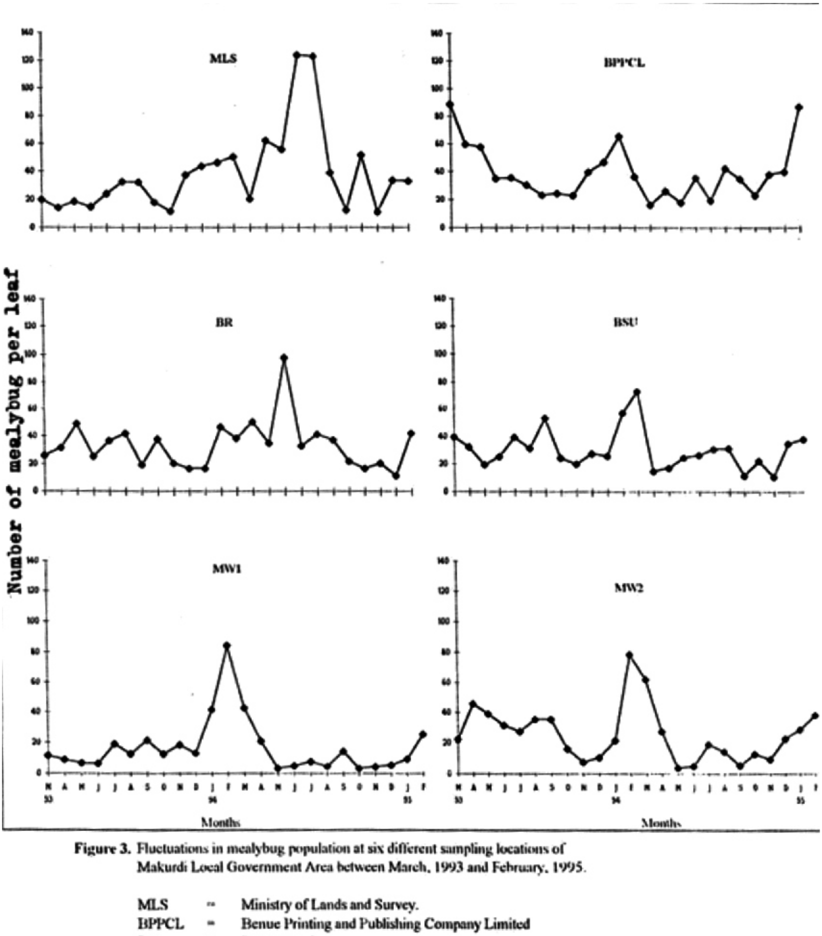


Figure 3. Fluctuations in mealybug population at six different sampling locations of Makurdi Local Government Area between March, 1993 and February, 1995.

MLS	=	Ministry of Lands and Survey.
BPPCL	=	Benue Printing and Publishing Company Limited
BR	=	Banks Road
BSU	=	Benue State University
MW_1	=	Mission Ward One.
MW_2	=	Mission Ward Two.

Also, it was observed that high wind speed when combined with rainfall reduced the population of the mealybug but when combined with the rainless period in the dry season contributed to its spread and population build-up (Figure 4).

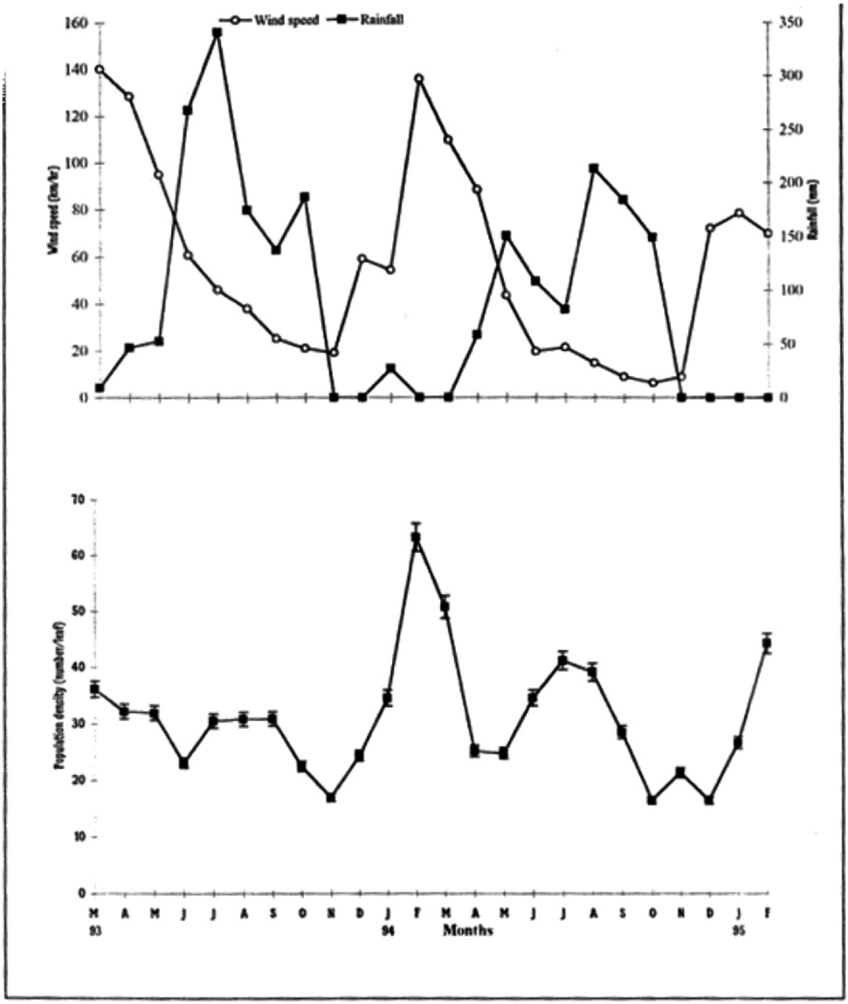
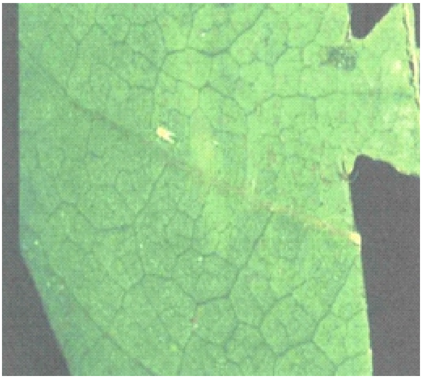


Figure 4(a). **Trend in the mean monthly population of R. invadens and weather elements (rainfall and wind speed) obtained in Makurdi Local Government Area between March, 1993 and February, 1995. Bars represent mean differences (+S.E) in density of the mealybug from six locations.**

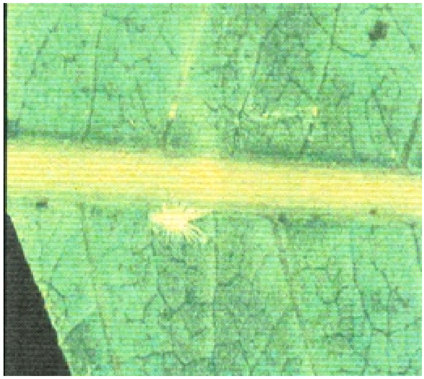
Between December and June, mostly dry period with low relative humidity and high temperature, *R. invadens* population increased. But, between July and October, when there was a heavy rainfall in the region, *R. invadens* population was generally low. This increase in the mealybug population during dry period and decline in their number during rainy period was also observed by Agounke *et al.* (1988). It was observed that *R. invadens* population fluctuated along with temperature and relative humidity conditions of the environment. Although the direct effect of these abiotic factors on the parasites was not like that of their host mealybug. Such fluctuation in the mealybug population also affected the parasite population. Chacko *et al.* (1986) found that at low relative humidity, *A*nagyrus antoninae failed to develop when released for the control of *Antonina graminis.* Fabre (1981) and Schulthess *et al.* *(*1987) observed that abiotic factors like rainfall was responsible for reduction in cassava mealybug, *Phenacoccus manihoti,* population. This clearly showed that both abiotic factors (rainfall, temperature and winds) and biotic factors (parasitoids and predators) are partly responsible for reduction in mealybug population. This agrees with the observation of Agricola *et al.* (1989) that both climate and parasitoid, *G. tebygi,* do jointly act to cause decline in *R. invadens* population level. Field composition of mealybug population consist of higher proportion of both first and second instars compared to other life stages. Willink and Moore (1988) and Moore and Cross (1992) discovered that these first and second life stages serve as main hosts to *G. tebygi.* Despite the presence of this parasitoid in the area of study, the two life stages in the presence of parasitoid probably suggests ineffective control of the mealybug.

3.4. Effects of host plants species on the reproductive parameters of *R.invadens*

R.invadens exhibits ovoviviparous form of reproduction. Mating occurs between male and female as soon as the alate male make contact with the adult female. Plate 1 shows the life cycle of *R.invadens* on different hosts plants.



Crawler



Second instar nymph

Pre-pupa male

Third instar female

Adult female

Adult male

Plate 1: life cycle of *R. invadens* (stages 1-6)

Table 3 shows the reproductive parameters of *R. invadens* on eight (8) different host plants species. They were significant (P <0.01) differences in the mean pre-reproductive period of female *R. invadens* reared on different host plant species. The pre-reproductive period on *N. oleander* was significantly longer than those obtained from females reared on other host plants. It was significantly shorter on *M. indica, S. nobilis, C. sinensis and E. umbellata* than on *P. alba*. *D. maculata* and *G. pictum.* The shortest pre-reproductive period of twelve (12) days was recorded on *S. nobilis* and the longest, 38 days, was obtained on *C. sinensis*. (Table 3)

Table 3: Effect of host-plants on the reproductive parameters of R. invadens in the Guinea Savanna

Host-plants	Mean pre-reproductive period (days ± S.E.) of female R. invadens	Mean reproductive period (days ± S.E.) of female R. invadens	Mean number (±S.E.) of crawlers produced	Mean longevity (days ± S.E.) of female R. invadens
Mangifera indica	19.81ab ± 1.18	35.4a ± 6.60	99.1c ± 14.38	59.3b ± 6.64
	14 - 30	11.81	27 - 223	30 - 106
Citrus sinensis	20.60b ± 1.79	39.9b ± 5.30	57.3ab ± 9.30	58.5b ± 4.98
	13 - 38	10 - 75	20 - 142	33 - 91
Ficus umbellata	22.0b ± 1.40	39.8b ± 6.26	139.7d ± 11.86	60.5b ± 5.93
	14 - 33	21 - 81	35 - 198	27 - 93
Plumeria alba	23.5c ± 1.05	43.3b ± 6.26	85.6bc ± 13.31	59.6b ± 7.01
	18.31	17 - 78	19 - 180	17 - 101
Dieffenbachia maculata	23.9c ± 0.96	42.7b ± 5.87	71.2b ± 10.18	53.9ab ± 6.70
	19 - 31	20 - 74	18 - 153	25 - 94
Graptophyllum pictum	24.60c ± 1.10	30.0a ± 3.64	52.0a ± 9.38	48.1a ± 4.98
	18 - 32	10 - 51	18 - 130	15 - 70
Sanchezia nobilis	18.30a ± 1.10	39.3b ± 5.86	87.2bc ± 13.86	63.0b ± 6.03
	12 - 26	15 - 72	15 - 184	36 - 96
Nerium oleander	26.90d ± 1.45	35.1a ± 4.71	88.4c ± 12.04	57.0b ± 4.40
	16 - 36	17 - 58	28 - 205	29 – 84

Means followed by the same letter are not significantly different at 1% level (DMRT)

There were significant differences in the mean crawler production periods recorded on the host plants. Crawler production periods was significantly longer on *F. umbellata, P. alba, D. maculata, S. nobilis and C. sinensis* than on *G. pictum.* Effects of different hosts plants species on crawler production was significant (P< 0.01). The number of crawlers produced on *F. umbellata* was significantly higher than those produced on other host plants species. The number of crawlers produced on *G. pictum* and that recorded on *C. sinensis* were not significant compared to the values obtained on other host plant species. Number of crawlers recorded on *M. indica* was significantly higher than that obtained on *D. maculata* and *C. sinensis*. Overall, the highest number of crawlers was produced on *M. indica (223)* and the least on *S. nobilis (15.)*

Significant differences (P < 0.01) were observed in the mean longevity (days) of adult female recorded on different plants. Overall, the longevity of adult females was highest on *M. indica (106* days) and lowest on *G. pictum (15* days) Adult males lived for only 2 days.

Morphologically, it is not possible to distinguish the male from the female during the first and second instar stages. The third instar male that emerge (after moulting) from second stage gradually covered itself with white wax to form an inhabited cocoon which distinguished it from the third instar female (Table 4).

Table 4: Developmental period (days) of instars stages of *R. invadens* reared on eight different host plants in Guinea Savanna

		Instar stages			
Host Plants	Sex	I	II	III	Mean
M. indica	female	9.8	9.3	8.8	9.3a
	male	9.7	9.2	11.8	10.2a
C. sinensis	female	10.6	8.8	11.7	10.4a
	male	10.4	8.7	12.1	10.4a
F. umbellate	female	8.8	8.4	10.2	9.1a
	male	9.7	8.5		10.0a
P. alba	female	9.8	9.8	9.7	9.8a
	male	9.8	9.4	11.9	10.4a
G. pictum	female	9.6	8.3	10.1	9.3a
	male	9.9	9.0	12.2	10.4a
D. maculata	female	9.3	8.8	9.9	9.3a
	male	9.3	8.4	11.6	9.8a
S. nobilis	female	10.5	8.3	9.4	9.4a
	male	10.7	8.6	10.2	9.8a
N. oleander	female	8.6	8.6	9.5	8.5a
	male	9.0	7.5	12.5	9.9a
Mean	female	9.6a	8.7a	9.9a	
	male	9.8a	8.7a	11.8b	

Means followed by the same letter are not significantly different at 1% level (DMRT)

The pupal case of the advanced form of pupal male is irregularly cylindrical with small lateral processes at the posterior end. Table 4 shows the developmental periods of the instar stages of *R. invadens* on eight (8) different host plant species.

The host plants show significant (P <0.05) influence on survival of the instars.

The mean percentage survival is highest on *N. oleander* (87.6%) and lowest on *G. pictum (64.8%).* In general, survival rate of the insects increased as the instars gradually advance in age. However, on *M. indica,S. nobilis* and *D. maculata* more of the first instars survived than either the second or third instars. It was also observed that more female instars died as compared to male instars. During screening of different host plant species for the reproductive study, red acalifer and guava did not favor successful development of *R. invadens.*

3.5 LEAF FEATURES AND SURVIVAL OF *R. INVADENS*

Adult females of *R. invadens* lived for mean shortest period of 4 8.1+4.98 days and had the least survival period on *G. pictum* compared to those of other seven host plants. *R. invadens* development (growth) and survival was least favoured by *G. pictum* where it recorded the shortest period, 30.0 days, of crawler production period compared to other tested host plants.

Leaf features, variegation and small leaf size, associated with *G. Pictum* are not quite common with other host plants used for the reproductive studies. Such features might have contributed to reduction in most reproductive parameters obtained on this host plant compared to those recorded on others. Tingle and Copland (1988), on the basis of leaf area recorded differential level of infestation of *Planococcus citri* on different host plants, being more on *Cristolochia and* Passiflora plants and lower on Vesneriacceae plants.

***3.6. R. INVADENS* POPULATION ON FIELD MANGO VARIETIES**

The present study has established the extent of spread and seasonal distribution of *R. invadens* on eight different varieties of mango among human settlements in the Guinea Savanna. The result of food sampling showed that each mango variety support the population growth of *R. invadens* with varying degree with John variety showing the least and insignificant support. The reason for extremely low infestation of *R. invadens on John even* while in the vicinity is not clear (Figure 5).

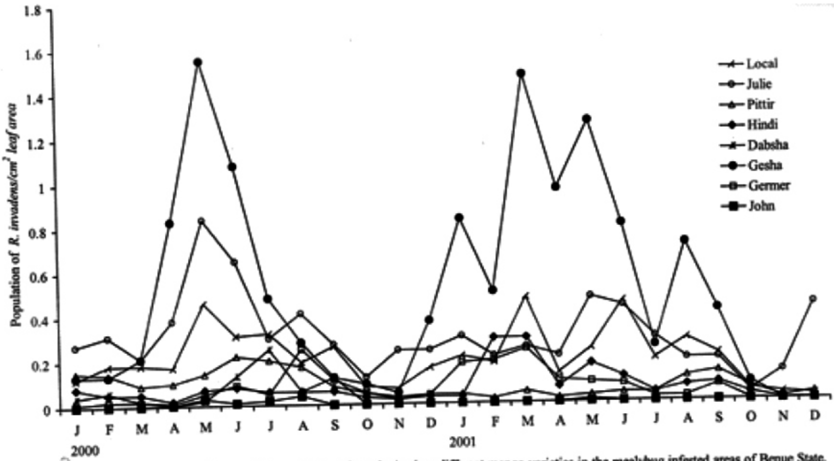


Figure 2: Trend in the mean monthly population of *R. invadens* obtained on different mango varieties in the mealybug infested areas of Benue State.

Figure 5: trend in the mean population of *R. invadens* on different mango varieties in the mealybug in the infested area of Benue state.

Although the exact age for individual tree considered for the field sampling was not documented, personal investigation showed that John variety was much older compared to other varieties. Leaf water (% fresh weight) and nitrogen (% dry weight) of terrestrial trees are known to decline with age (Scriber and Slansky, 1981). Age of such advanced tree (not less than 45 years) could influence level of its physiological function, moisture factors and physical features of leaf which may be responsible for such low infestation (Soo Hoo and Frankael, 1966) although the factors themselves were not investigated during course of this experiment.

In this study, *R. invadens* population density increased with increase in number of leaves per flush and decreased with increase in leaf area (or leaf size) among the mango varieties. Thus the closer leaves per flush

(Gesha) and the smaller the leaf (or leaf size) among the mongo varieties the higher the mealybug population density. This finding tally with what Tingle and Copland (1988) recorded for *Planococcus citri* on different two plants, being more on *Aristolochia* and *Passifora plants* and lower on Vesnerriaceace plants. Leaf size is probably an important variable that could influence *R. invadens* population since leaves from other varieties have smaller leaf areas and much greater mealybug population density to indicate a negative correlation Gesha variety with closel set leaves had greater population of the mealybug than other varieties. The higher population of *R. invadens* on *M. indica* than the other experimental host plant species could also be attributed to the fact that *M. indica* , invariably had more closely set leaves than the other than the other said plant species. In this regard, obviously, *M. indica* with closely set leaves will favour greater spread and increase of the mealybug than other host plant species with sparsely distributed leaves. Also, John variety has the largest leaf area compared to other varieties. The number of *R. invadens* per cm2 leaf area of this variety is lowest compared to those recorded for other varieties with smaller leaf areas. Determination of *R.* invade*ns* population density in terms of number of mealybug per cm2 leaf area instead of per leaf is to give a sound basis for easy comparison of the population (Local species) as the most favorable host of this pest (Figure 6).

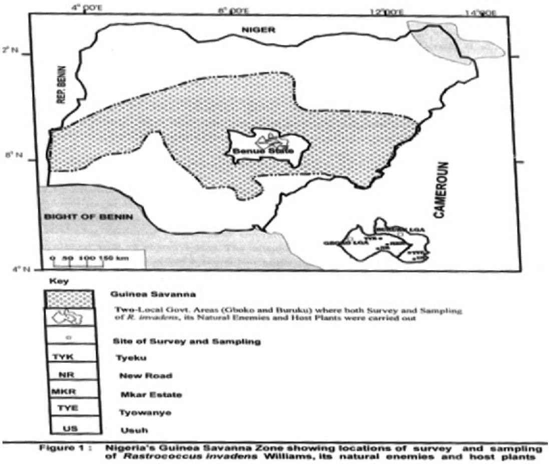


Figure 6: Nigeria's Guinea savanna Zone showing locations of survey and sampling of *Rastrococcus invadens*(Williams), its natural enemies and host plants.

A number of leaf structures (or features) including leaf size and juice (or chemical constituents) were listed as variables that could influence increase in insect population (Boethel and Eikenbary, 1986).

Within the two years study period the mealybug attained its population peak about the month of May which is usually the beginning of rains, and declined sharply towards the month of October. This might probably be due to joint forces of wind and rainfall characteristic of this zone, among (stormy weather) could have probably accounted for similar sharp decline in the mealybug population from its bi-modal peaks observed on Gesha variety in the second year. Such drastic reduction in *R. invade*ns population on each variety due to the washing-off of the pest from the leaves by the windy rain conditions could for a long period limit a reasonable increase in natural population of the pest except in a situation where the environmental conditions are highly favorable for its growth as was on Gesha variety.

3.7. BIOLOGY OF *R. INVADENS* ON MANGO VARIETIES

Plate 2 shows sleeve cages used for the study of biology of *R. invadens* on different mango varieties

Plate 2: A set of 50 X 62 X 106 cm sleeve cages with different mango varieties raised for field study of the biology of *Rastrococcus invadens*

Nerium oleander and Ficus spp. (Laup, 1987; Narasimham and Chacko, 1988). Although the varieties like Dabsha and Pittir were not used in the reproductive study because the buds failed to establish after grafting, all the different stages of the mealybug were obtained from every mango varieties during field studies. Pre-reproductive period of *R. invadens* was significantly shorter on John, Gesha and Local varieties, from experience they produced fresh leaves more frequently than the other varieties used (Table 5).

Table 5: Effects of different mango varieties on the reproductive parameters of *R. invadens in the Guinea Savanna*

Mango varieties	Mean pre-reproductive period (days ± S.E.) of female *R.invadens*	Mean reproductive period (days ± S.E.) of female *R. invadens*	Mean number (x ± S.E.) of crawlers produced	Mean longetivity (days ± S.E.) of female *R. invadens.*
Local	19.57 ± 1.11$_b$	35.70 ± 4.70$_a$	102.23 ± 14.25$_a$	58.93 ± 5.63$_a$
	14 – 31	11 – 81	25 – 230	24 – 106
Julie	22.93 ± 1.20$_a$	32.83 ± 3.72$_{ab}$	57.87 ± 8.12$_a$	35.73 ± 3.50$_d$
	15 – 29	10 – 54	21 – 120	18 – 58
John	18.70 ± 0.95$_b$	27.78 ± 2.02$_{abc}$	67.27 ± 9.95$_{bc}$	44.20 ± 2.51$_c$
	12 – 27	11 – 46	22 – 167	19 – 65
Germer	24.57 ± 2.43$_a$	23.73 ± 2.10$_c$	53.70 ± 6.89$_a$	53.27 ± 3.34$_b$
	12 – 36	9 – 39	28 – 100	30 – 73
Gesha	20.47 ± 0.87$_b$	26.37 ± 2.30$_{bc}$	75.43 ± 9.00$_b$	44.03 ± 2.88$_c$
	15 – 26	15 – 26	22 – 216	15 – 62
Hindi	20.73 ± 1.39$_b$	20.73 ± 3.96$_c$	61.90 ± 10.42$_{cd}$	39.70 ± 3.39$_d$
	14 – 33	10 – 61	20 – 117	20 – 64

Means in each column followed by the same letter are not significantly different at 5% level (DNMRT).

Indeed, Singh (1968) seems to be in tune with previous reports that pre-reproductive female mealybug preferred newly produced leaves. (Boavida and Neuenschwander, 1995) which usually contained higher nitrogen and phosphorus levels than occurred in more matured leaves (Nafus, Schrainer and Dumaliang, 1991).

In terms of number of crawlers produced per female, developmental period, adult longevity, pre-adult survival, Local mango variety seems to be the most preferred host plants with John and Gesha varieties ranking next. This inherent nature of this Local variety that could make it adequate food for the female to produce crawlers at a shorter duration after emergence and to live longer and produce higher number of crawlers compared to others has proved the variety as the most preferred host (Table 6).

Table 6: Developmental period (days) of nymphal instars of *R. invadens* reared on six different mango varieties in Guinea Savanna.

Mango Varieties	Instars (immature stages) I		II		III		Mean total developmental period	
Local	9.8b	9.7b	9.4a.	9.1a	8.8c	11.6c	28.9cd	30.4a
Julie	9.8b	9.9b	9.1b	9.3a	9.1bc	12.4ab	28.3d	29.1a
John	9.7b	9.3c	9.2ab	9.1a	9.4b	11.3c	29.3bc	30.1a
Germer	11.0a	11.0a	8.9b	9.2a	9.4b	12.6ab	29.7b	30.3a
Gesha	9.8b	9.9b	9.2ab	9.2a	10.0a	11.9bc	29.7b	30.3a
Hindi	9.4b	9.9b	9.4a	8.9a	10.2a	12.8a	30.7a	30.4a

Means in each column followed by the same letter are not significantly different at 5% level (DNMRT).

The developmental time for the third instar male was much longer compared to that of female on every variety. This longer time of development for this instar larva may arise because of its second moult and next stage (or second stage) pupal male which occurs and undergoes transformation before the emergence of adult male (Table

Table 7: Percentage survival of larval instars of *R. invadens* recorded on six varieties of mango from field sleeve-cage study

Mango varieties	Survivorship of larval instars I	II	III	Pupa	Mean
Local	80.0a	71.0b	74.6a	76.6a	75.6a
Julie	47.0a	43.7d	66.8a	68.2a	56.4b
John	74.6a	78.0ab	76.7a	77.5a	76.7a
Hindi	68.4a	64.99bc	57.2a	60.0a	62.6b
Gesha	87.2a	85.9a	84.8a	84.2a	85.4a
Germer	57.4a	55.9cd	63.3a	65.0a	60.4b

Means in each column followed by the same letter are not significantly different at 5% level (DNMRT).

Although the male time of development reported by Willink and Moore (1988) and Chacko *et al.* (1986) was also longer than that of the females reared on young citrus plant in a glass house experiment, the duration in time of development from the two experiments are not quite close, and that obtained from every mango variety in this present study was longer than that observed from citrus .This clearly wide margin in time of development could be attributed to differences between the two plants which belong to different plant families and the differences in conditions under which the two experiments were carried out.

3.8. IMPACTS OF *R. INVADENS* ON MANGO SEEDLING

Although significant effect of the mealybug population on the growth in height and leaf numbers were not recorded in this study there were high negative correlation between *R. invadens* population level and each of the two parameters, which was also an indication of a negative impact on the growth of the seedlings (Table 8).

Table 8: Effects of varying populations of R. invadens on the height and number of leaves of infested mango seedlings during the period of right weeks.

Treatments (rate of infestation)	Increase in height and number of leaves at: 2 weeks period, Height (cm.)	2 weeks period, No. of leaves	4 weeks period, Height (cm.)	4 weeks period, No. of leaves	6 weeks period, Height (cm.)	6 weeks period, No. of leaves	8 weeks period, Height (cm.)	8 weeks period, No. of leaves
0 (un-infested control)	6.46±1.85 (3.1-10.2)	10.60±1.42 (6-13)	7.80±2.33 (3.1-10.2)	12.2±1.76 (4.2-14.9)	9.32±2.68 (4.2-14.0)	14.00±3.55 (8-14)	14.00±3.55 (5.2-20.8)	14.00±2.25 (12-19)
4 adult females	6.46±1.52 (2.9-10.7)	8.80±1.16 (4-9)	7.10±1.72 (3.2-12.1)	12.2±1.29 (8-17)	8.10±2.07 (4.3-13.8)	12.2±1.43 (12-17)	10.10±2.85 (5.8-18.0)	13.80±1.78 (11-8)
8 adults females	5.50±1.49 (1.70-8.00)	7.4±1.14 (6-9)	5.96±1.73 (1.80-8.90)	9.40±1.31 (7-12)	6.28±1.98 (1.90-9.20)	11.00±1.37 (8-15)	6.98±2.33 (2.80-9.70)	11.60±1.46 (8-15)
16 adult females	5.44±1.72 (4.00-8.00) ns	6.60±1.32 (16-15) ns	5.82±27 (4.00-8.10) ns	8.60±1.71 (6-10) ns	3.58±3.03 (1.20-6.80) ns	9.80±2.09 (7-14) ns	4.82±4.77 (2.20-8.50) ns	9.60±2.98 (7-13) ns
R	-0.013* 0.04*	-	-0.15*	-0.44	-0.38*	-0.22*	-057	-0.52

ns = not significantly different at 5% level.
r = regression inefficient at 5% level
* = regression inefficient not significant

It is also evident from the results of these studies that within eight weeks after infestation 4-16 larvipositing females could produce progeny (population or offspring) that is capable of causing significant damage to the physiology of mango seedlings. *R. invadens* is thus proved to be a serious pest of mango on the basis of its significant impact on the plant physiology. Reduction in the chemical content of leaves caused by *R. invadens* could be due to reduced growth in height and leaf numbers per plant decreased as the infestation level increased with time, a negative impact on plant growth by the mealybug has therefore been observed. Such growth reduction by *R. invadens* was earlier reported (Neuenschwander *et al.,* 1993), especially during high infestation. Such high infestation has at certain time misled some farmers to cut down infested shoots or dense canopies in such a manner that general growth and fruit production were badly or negatively affected (Bokonon-Ganta and Neuenschwander, 1995). Although the effect of black sooty moulds associated with honey dew secreted by *R. invadens* was not quantified (or assessed) in the study Neuenschwander (1989) and Atusuiba (1990), have reported that the photosynthetic surface of leaves are greatly infected or covered by the moulds in case of high infestation. This may subsequently lead to decrease in the level of carbohydrate manufactured with consequent effect on growth as well as fruit yield in the host plant.

3.9. IMPACT OF THE MEALYBUG ON THE CHEMICAL CONTENT OF MANGO LEAVES

High reduction in chlorophyll content in leaves of infested plants compared to that of control plants was observed. This reduction in chlorophyll content may be due to death of palisade cells associated with chlorophyll pigments consequent to attack by the mealybug. This reasoning tends to agree with the report of Edmond *et al. (*1988) that the level of chlorophyll production is reduced when mealybug spp. pierced the epidermal layer and suck the tiny chloroplasts, soluble foods and vitamins from the leaves. Similar damages was reported for the euonymous scale, Unaspi *euonymi* Comstock (Cockfield *et al.,*1987). According to Letchamo and Gosselin (1995), increased chlorophyll content could also ensure increased photosynthesis. This might mean therefore that reduction in chlorophyll content could lead to reduction in carbohydrate (or sugar) production in the affected plant (Table 9).

Table 9: Effects of varying population of *R. invadens* on the chemical contents of leaves of infested mango plants at eight weeks after infestation

Treatments (rate of infestation)	Chemical contents: % moisture content	Quantity of chlorophyll (mg/g fresh leaf)	Quantity of sugar (Glucose in g/100g fresh leaf)	% crude protein (dry weight basis)	% ash content (dry weight basis)	% crude fibre (dry weight basis)
0 (un-infested control)	63.65a ±0.96 (63.20-64.00)	0.8990a ± 0.08 (0.894-0.941)	1.545a ± 0.10 (1.270-1.760)	8.050a ± 0.16 (7.440-8.380)	7.697a ± 0.17 7.180-8.090)	23.845a±0.07 (23.740-24.000)
4 adult females	62.06a ± 0.78 (61.57 - 6255)	0.7923a ±0.07 (0.846 - 0.923)	1.195b ± 0.08 (1.110 - 1.280)	7.955a ± 0.13 (7.880 - 8.000)	6.865b ± 0.14 (6.840 - 6.920)	22.760b ± 0.05 (22.700 - 22.800)
8 adults females	61.40a ± 0.66 (60.00-61.60)	0.7573a ± 0.06 (0.725 -0.789)	0.863c ± 0.07 (0.810 -0.910)	6.675b ± 0.11 (6.630 - 6.750)	6.472c ± 0.16 (6.250 - 6.770)	22.330c ± 0.05 (21.980 -22.440)
16 adult females	60.60a ± 1.24 (60.00 -63.60)	0.6425a ± 0.11 (0.616 -0.669)	0.825c ± 0.12 (0.820 -0.830)	5.190c ± 0.20 (5.000 - 5.380)	5.980d ± 0.22 (5.880 - 6.210)	22.210c ± 0.09 (22.180 -22.400)

Means followed by the same letter are not significantly different at 5% level (DMRT)

Crude protein level decreased with Increased mealybug number. A similar negative correlation in the reduction in crude protein content of alfalfa with increasing mealybug number was reported by Hower and Flinn (1986). Also, analysis of pea phloem sap that has been sucked by pea aphid, *Acyrthosiphon pisum* Harris showed significant reduction in amount of amino acids (Barlow and Radolph, 1978) which is the form of protein absorbed by the insect from the phloem sap. Percent ash content decreased with increased level of mealybug infestation. This suggests that the mineral required by the plant decreased with the increase in the level of infestation.

4.0 ESTABLISHMENT OF *G. TEBYGI* ON ITS HOST MEALYBUG

G. tebygi was recorded from all the six sampling sites even during unfavourable conditions (i.e. stormy weather) between March and May when *R. Invadens* population density was low. This finding clearly showed that *G. tebygi is* well established in Guinea Savanna which lies in the drier and hotter part of the country compared to a more humid South West where the parasitoid was initially released (Figure 7).

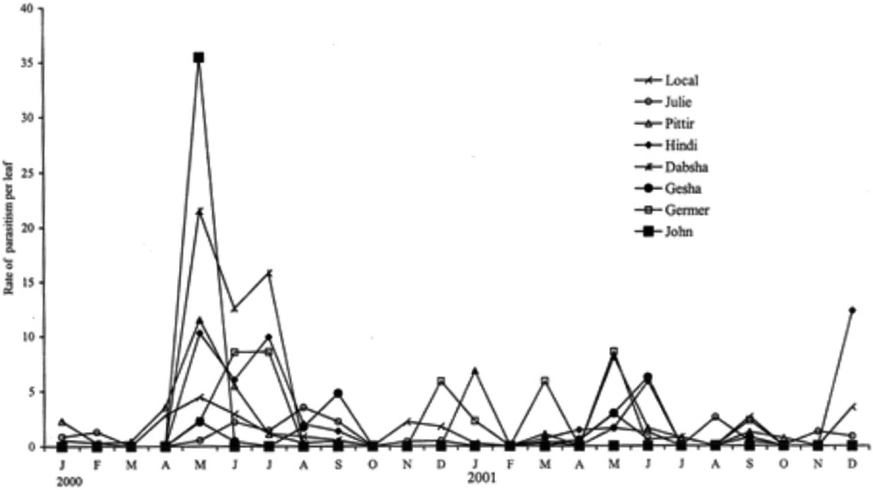


Figure 7: changes in the level of parasitism of *R. invadens* by *G. tebygi* on eight different mango varieties in mealybug infested areas of Benue state between January 2000 and December 2001.

This observation agrees with the report of Agricola *et al.* (1989) that the parasitoid could be established in different ecological conditions ranging from cooler coastal to hotter arid region. Neuenschwander (1989) and Boavida *et al.* (1992) have similarly reported easy field establishment of *G. tebygi* in Togo, Ghana, Benin, Gabon and Zaire .

4.1. LOW RATE OF PARASITISM OF *R. INVADENS*

The rate of parasitism of *R. invadens* by the parasitoid, *G. tebygi* was generally very low, being higher on mango varieties with low infestations and less on those with high infestation. The very low level parasitism of *R. invadens observed* in this study can be explained from the fact that the parasitization determined in this work has to do with only the mortality caused to the mealybug by oviposition and development of the immature stages of the parasitoid in the host, and also the reduction of the number of primary Parasitoid by the hyperparasitoids (Table 10).

Table 10: Regression statistics of one variable, *G. tebygi* that influenced the mango mealybug populations on six mango varieties.

Mango varieties	Regression Statistics			
	t_b values			
	G. tebygi	R^2	R	Fcal
Hindi	1.320	0.073	0.271	1.743
Gesha	2.217*	0.183	0.427	4.913*
Julie	2.358*	0.202	0.449	5.56*
Local	2.516*	0.223	0.473	6.328*
Pittir	3.636*	0.375*	0.613	13.217*
Germer	2.529*	0.225	0.475	6.394*

* Significant at $P = 0.05$

Furthermore, the population curve on different host plants revealed that *G. tebygi* increase in number was much dependent on the significant increase of its host *R. invadens* population, an observation which shows that the parasitoid was not effective enough in its role as bio-control agent of the mealybug.

Hyperparasitism of G. tebygi observed in this study though generally high may not alone account for such a low parasitism level vis-à-vis relatively high R. invadens population on some host plants since the only form of parasitism considered in this study was that in which the parasitoid caused mortality by developing inside the host mealybug (Figure 8 and 9).

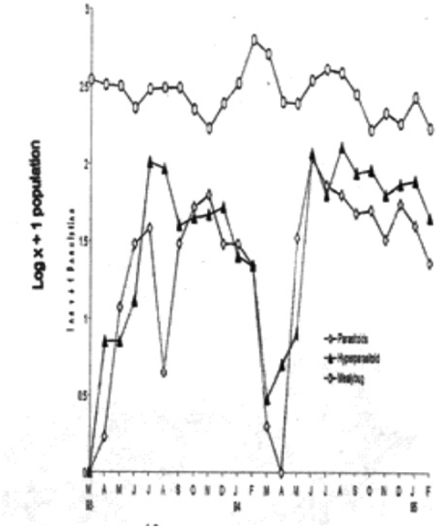


Figure 8: Fluctuations in mealybug population, its primary and secondary parasitoids obtained from six different sites in Makurdi local government Area between March, 1993 and February 1995

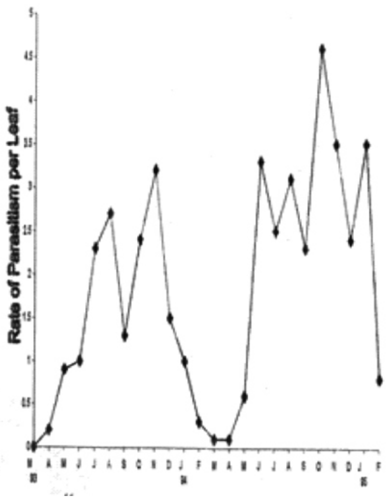


Figure 9: Changes in the level of parasitism of *R. invadens* by its parasitoids, *G. tebyigi,* on mango trees at six different sampling sites in Makurdi local Government Area between March 1993 and February 1995

The fact that the negative influence of the hyperparasitoids on the parasitoid was not too obvious from the population curves may be probably due to their low number in the field. However, overall percentage reduction in parasitism of the parasitoid of 43.5 % (range 10-66.6) could definitely limit the success of a parasitoid.

4.2. HYPERPARASITOIDS AND THEIR IMPACT ON *G. TEBYGI*

One of the objects of the present studies was to determine the identity and relative importance of the indigenous hyperparasitoids of *G. tebygi*. These hyperparasitoids: Marietta *leopardina*, *Chartocerus hyalipennis, Tetrastichus* sp., P*rochiloneurus eagyptiacus* and *Cheiloneurus* sp. recorded posed some restrictions to the control of *R.*

invadens by its parasitoid, *G. tebygi* and were also previously reared from mummified *P. Manihoti* by Neuenschwander*et al.* (1987). Agricola and Fischer (1991) reported that *G. tebygi* and *E. lopezi* were both attacked by a similar group of hyperparasitoids most of which were identified with *E. lopezi* from many African Countries (Neuenschwander *et al.,*1987) (Table 11)

Table 11: Total emergence for each of the primary and secondary parasites and percentage reduction in number of primary parasitoid *of R.* invadens by hyperparasites on mango trees in Makurdi Local Government Area.

Site	Total number of mummies	No. of primary parasitoid (*G.tebygi*)	Secondary parasitoids					% reduction in number of primary parasitoid
			Tetrasichus spp.	*M. Leopardina*	*C. hyalipennis*	*P. aegyptiacus*	*cheiloneurus* sp.	
MLS	269	107 (39.8)	17 (6.3) 10.5**	78 (29.0) 48.2**	38 (14.1) 23.5**	6 (2.2) 3.7**	23 (8.6) 14.2**	60.2
BPPCL	193	90 (46.6)	2 (1.0) 1.9**	86 (44.6) 83.5**	15 (7.8) 14.6**	0 (0)	0 (0)	53.4
BR	215	90 (41.1)	6 (2.7) 4.8**	86 (39.3) 68.8**	30 (13.7) 24.0**	3 (1.4) 2.4**	0 (0)	57.1
BSU	264	100 (37.9)	28 (10.6) 17.1**	117 (44.3) 71.3**	17 (6.4) 10.4**	2 (0.8) 1.2**	0 (0)	62.1
MW_1	136	64 (47.1)	9 (6.6) 12.5**	32 (23.5) 44.4**	27 (19.9) 37.5**	4 (2.9) 5.6**	0 (0)	52.9
MW_2	184	74 (40.2)	42 (22.8) 38.2**	32 (17.4) 29.1**	29 (15.8) 26.4**	7 (3.8) 6.4**	0 (0)	59.8

** Percentage contribution to secondary parasitism.
Figures in parendesis = % of total mummies.

MLS	=	Ministry of Land and Survey.
BPPCL	=	Benue Primary and Publishing Company Ltd.
BR	=	Bank Roads
BSU	=	Benue State University
MW_1	=	Mission Ward One.
MW_2	=	Mission Ward Two.

Both Hayat (1974) and Neuenschwander (1987) also discovered that these secondary parasitoids occurred on a number of other primary parasitoids from different coccoid species.

This suggests therefore that the secondary parasitoids associated with *G. tebygi* in this study are polyphagous. But, despite the non-host-specificity as reported among the secondary parasitoids, population curves of the total secondary parasites compared to those of *G. tebygi* at different sites of sampling indicating that well above 50% of the entire parasite number were hyperparasites (Table 12).

Table 12: Total emergence for each of the primary and secondary parasites and percentage reduction of primary parasitoid of *R. invadens* by hyperparasites on eight different mango varieties in the mealybug infested areas of Benue State.

Mango Varieties	Total number of mummies	No. of primary Parasitoid (*G.tebygi*)	Number of hyperparasitoids					% reduction in number of primary parasitoid
			Tetrasichus sp.	*M. leopardina*	*C. hyalipennis*	*Cheiloneurus* sp.	P. *aegyptiacus*	
Julie	19	10 (52.6)	1 (5.3) [11.1]	6 (31.6) [66.7]	1 (5.3) [11.1]	1 (5.3) [11]	0 (0)	47.4
Pittir	24	13 (54.3)	1 (4.2) [9.1]	6 (25.0) [54.5]	3 (12.5) [27.3]	1 (4.2) [9.1]	0 (0)	45.8
Hindi	17	7 (41.2)	1 (5.9) [10.0]	6 (35.3) [60.0]	3 (17.6) [30.0]	0 (0)	0 (0)	58.8
Local	22	10 (45.5)	0 (0)	7 (31.8) [58.3]	3 (13.6) [25.0]	1 (4.5) [8.3]	1 (4.5) [8.3]	54.5
Germer	10	9 (90.0)	0 (0)	1 (10.0) [100.0]	0 (0)	0 (0)	0 (0)	10.0
John	1	1 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0
Dabsha	13	6 (46.2)	2(15.4) [28.6]	3 (23.1) [42.9]	1 (7.7) [14.3]	0 (0)	1 (7.7) [14.3]	53.8
Gesha	40	26 (65.0)	3(7.5) [21.4]	7 (17.5) [50.0]	3 (7.5) [21.4]	0 (0)	1 (2.5) [7.1]	35.0

[ ] Percentage contribution to secondary parasitism
Figures in parenthesis = % of total mummies.

Although it is not certain whether the low parasitism index obtained for *G. tebygi was* mainly due *to* high hyperparasitism by the secondary parasites, overall average reduction in the number of primary parasites ranged from 52.9% to 62.1% (mean = 57.6 %) at different locations. This reduction in number of the parasitoid by hyperparasitoids is generally high, and tend to disagree with the report of Van den Bosch (1981) which says that hyper parasites may need to exhibit a high host specificity before they can have a negative impact on the biological control by a parasitoid.

M. leopardina, followed by *C. hyalipennis* contributed most to secondary parasitism in this area of study.

In a similar study on hyperparasitism of both *G. tebygi* and *E. lopezi in* Togo, *Chartocerus* sp. followed by *M. leopardina* contributed majorly to hyperparasitism of the two parasitoids (Agricola and Fischer, 1991). Also, in a laboratory trial, Moore and Cross (1992) identified the two as the major hyperparasites associated with *A. mangicola,* being more highly parasitized by *C. hyalipennis* than *G. tebygi*.

4.3. MULTI- AND SUPER- PARASITISM OF THE PARASITOID

A relatively few multi- and super- parasitism of *G. tebygi* were encountered throughout this study with *P. eagyptiacus* and *Cheiloneurus* sp. being only hyperparasites not involved in either of the two may be because of their rare field occurrence. Agricola and Fischer (1991) had recorded the emergence of *P. aegypiacus* and *C. hyalipennis fr*om on*e* mummy. Goergen (1988) reported that both super- and multi-parastisms are known to reduce success in the production of the secondary parasites although *such* negative effect on the reproduction might not be meaningful on the overall hyperparasitism observed in this study. Also, multi- parasitism involving two to four *C. hyalipennis* and two *M. leopardina* emerging from one mummy was recorded in this study. Although Moore and Cross (1992) recorded the emergence of some two to four *C. hyalipennis* from one mummy, that of two *M. leopardina* from a single mummy was not encountered in their studies. This observation has therefore shown that both *C. hyalipennis* and *M. leopardina* were gregarious among the hyperparasiitoids.

4.4. INDIGENOUS PREDATORS AND *R. INVAD*ENS

The indigenous predators observed in the Savanna were generally very low in numbers compared to that of the parasitoid. They were recorded from the field mostly when the level of their host mealybug, *R. invadens,* significantly increased. This positive relationship between the predators and their mealybug is similar to observation by Hammond and Neuenschwander (1990) that indigenous predators are only attracted to cassava mealybug, *P. manihoti,* at *a* high population density. While *E. promptus* and *S. lemolea* among others observed in Guinea S*avanna* were reported on *R. invadens* in Togo (Agounke *et al.,* 1988) and Southern Nigeria (Ivbijaro *et al., 1992*), *C. distigma* and *Ceratochrysa* sp. were not so far reported on *R. invadens* from elsewhere in Africa. But, all the present predators were at different time recorded on the already existing mealybug species in Africa. For instance, Neuenschwander *et al.* (1987) recorded *S. iemolea* on *P. manihoti, P. madeirensis* and *F. virgata.* On a similar note, Agounke *et al.* (1988) reported that the indigenous predators of *R. invadens* have become adapted to already existing mealybugs in Africa. This lack of host specificity observed among the present predators may account for their low population level recorded on *R. invadens* (Figure 10).

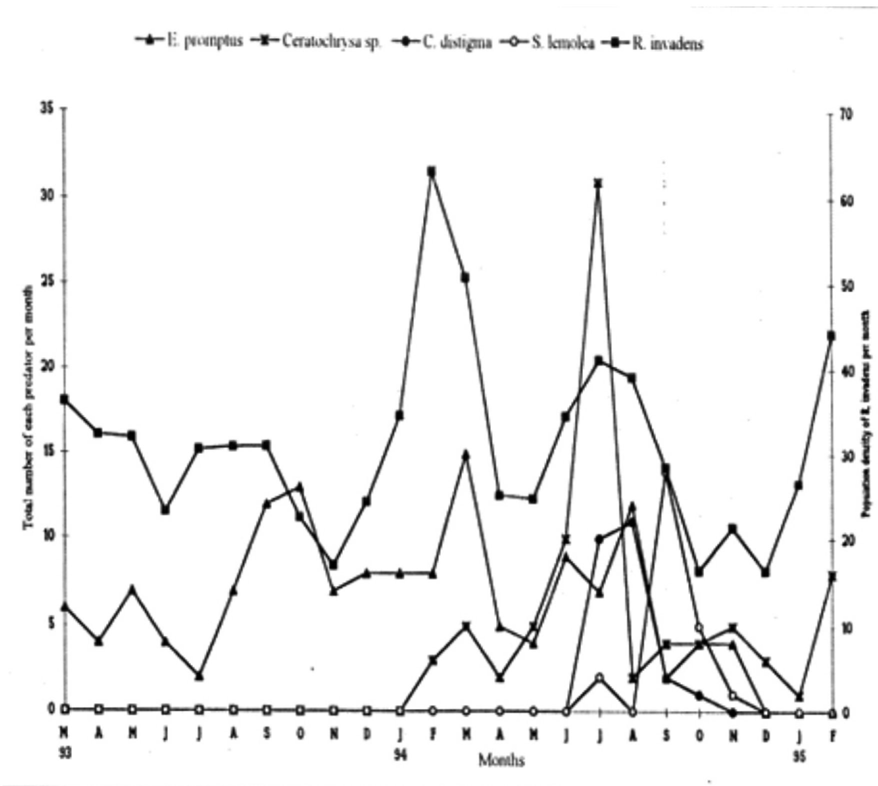


Figure 10: fluctuation in number of *R. invadens* predators over the period of 24 months (March 1993-February, 1995) in Makurdi local government Area

4.5. POLYPHAGY OF *R. INVADENS* AND DIFFICULTY IN ITS CONTROL

The present knowledge of *R. invadens* biology on selected species of fruit trees, flowers and ornamentals in addition to its field population levels observed during the rainy- and dry- season periods may assist in its effective control at different level of ecosystem. This inherent nature of *R. invadens* to feed and survive on many host plants could make it more difficult to control especially as the mealybug is less or not parasitized by its host specific parasitoid *G. tebygi* on certain host plant species (Chacko *et al.,* 1986; Narasimham and Chacko, 1988).

4.6. RECOMMENDATION OF IPM APPROACH

In view of the significant impact of *R. invadens* on the performance of mango plant as observed in this study, high reduction in the number of its parasitoid by the activities of the hyperparasitoids and low predation by its existing predators, an integrated pest management approach has become necessary for effective control of the mealybug pest in the area. Therefore, the knowledge of different host plants, reproductive and developmental biology, and seasonal abundance acquired during both laboratory and field studies are quite essential for developing a timely control action against the mealybug, *R. invadens* in the Guinea Savanna of Northern Nigeria and other areas with similar ecology.

4.7. BOTANICALS FROM GUINEA SAVANNA TRIED FOR THE CONTROL OF THE MEALYBUG

In continuing to search for biologically active natural plant products from Guinea Savanna shrubs and trees, this study has shown the crude extracts of *Azadirachta indica, Anonna muricata, A. senegalensis, Zanthoxylum zanthoxyloides, Tephrosia vogelii and T. candida to be* insecticidal *to the* mealy bug with mortalities increasing with increase in concentrations of the extracts. Over 75% of the extracts screened against the mealybug during the experiment were highly insecticidal. The choice of adult female among the life stages as test insect for investigation of the efficacy of the extracts was to allow ease of handling and more so that the relatively small immature stages were killed faster than the adult female by the different solvents used for the preparation of the extracts. Perhaps, it might be justifiable to say that each of the bioactive extract that significantly killed the adult females is capable of eliminating more of the pre-adult stages which had a more relatively exposed (or naked) and soft body compared to immature stages treated with the same dosage levels of *Acorus calamus* rhizome and *Glycosmus mauritiana* root bark extracts (Bandara *et al.,* 1990).

4.8. EXTRACTS CONCENTRATIONS AND APPLICATION

The examination of the bioactivity of *T. vogelii* has indicated that all the four components screened were highly insecticidal to the mealybug. Hence, when screening therefore for bioactivity it is important to obtain as many different parts of the plant as possible for extraction (Table 13)

Table 13: Mean percentage mortality of adult female *R. invadens* treated with extracts of different parts of *T. vogelii.*

Extract concentration %	Percentage Mortality of Adults Treated with Extracts of			
	Leaf Extract	Root bark Extract	Seed Extract	Stem bark Extract
2	76.2b	41.0b	68.7b	83.4b
5	91.7a	81.3a	80.7b	86.7b
10	93.3a	85.0a	89.7a	94.7a
Standard Control	22.9c	20.3c	25.7c	28.0c
Control	23.3c	18.1c	11.9d	11.5d

Means within each column followed by the same letter are not significantly different at 5% level (DNMRT).

High insect mortalities obtained at 5% and 10% concentration for seed extract of *T. candida,* stem-bark and leaf extracts of *T. vogelii* were not significantly different even though *T. candida* extract performed best by contact mode of action, followed by *T. vogelii* stem-bark (Table 14).

Table 14: Percentage mortality of adult female *R. invadens* subjected to contact of extracts of *T. candida* and *T. vogelii.*

Extract concentration %	Percentage Mortality of Adults Treated with Plant Extracts				
	Seed (*T. candida)*	Seed *(T. vogelii)*	Root bark *(T. vogelii)*	Stem bark *(T. vogelii)*	Leaf *(T. vogelii)*
1	66.6b	-	-	-	-
2	80.5b	66.7c	38.5b	80.6b	78.6b
5	97.0a	78.6a	78.6a	90.0ab	94.4a
10	97.2a	87.2a	84.8a	97.2a	93.3ab
Standard Control	14.6c	28.4d	21.5c	30.8c	24.3c
Control	12.4c	12.1cc	18.2c	9.6d	19.5c

Means within each column followed by the same letter are not significantly different at 5% level (DNMRT).

It is also evident from the study that the seed extract of *T. candida* had *a* more systemic toxicity than the extracts from *T. vogelii and that of A. senegalensis* root-bark although its mortality at 1% concentration was not significantly different compared with standard control. *T. candida* seed extract*,* followed by *A. senegalensis* root-bark extract showed their superiority among the extracts tested on *R. invadens* displaying high level contact, systemic and fumigant toxicities in decreasing order of potency. **Figure 11** shows 48-h dosage mortality regression line for crude extracts from *T. vogelii* stem bark against adult female *R. invadens)*.

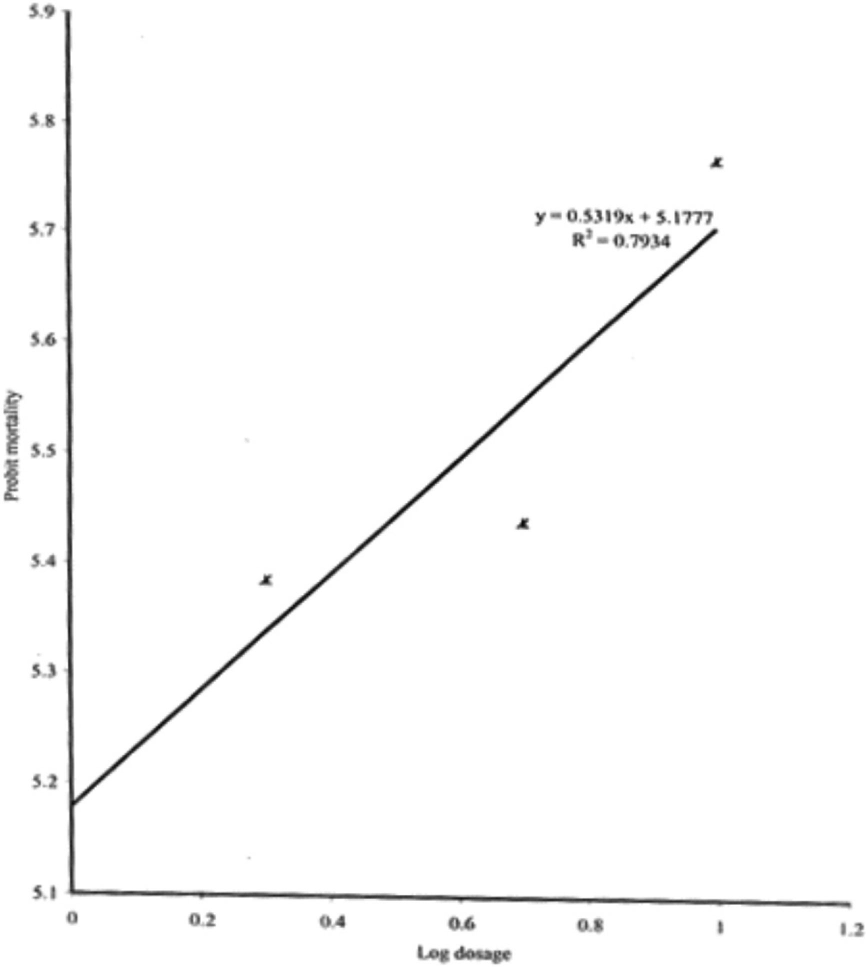


Figure 11: 48-h dosage mortality regression line for crude extract from *T.vogelii* stem bark (combined toxicity test) against adult female *R.invadens,* dosage in μg/insect

4.9. TOXICITY OF SEED OIL EXTRACTS ON ADULT *R. INVADENS*

Dilute concentrations (0.01-0.1%) of neem seed oil once recommended for the control of field insects (Lawrence *et al.,*1990) was tested along with *Anonna muricata seed oil on the* mealybug in this study. Although both oil extracts were quite effective, *A. indica* seed oil had a greater insecticidal effect on the mealybug than the other even at equivalent concentrations (Table 15).

Table 15: Percentage mortality of adult female *R. invadens* subjected to contact action of *A. indica* and *A. muricata* seed oils.

Extract concentration %	Percentage Adult Mortality	
	Neem seed oil (*A. indica*)	Annona seed oil (*A. muricata*)
0.01	83.3c	75.0b
0.02	91.7bc	83.3ab
0.05	97.2ab	86.1ab
0.1	100.0a	88.9a
Standard Control	13.9d	11.1c
Control	5.5d	9.7c

Means within each column followed by the same letter are not significantly different at 5% level (DNMRT).

Even though the broad spectrum pesticidal nature of neem extracts (including NSO) coupled with their low toxicity to several species of beneficial insects have been reported (Lawrence *et al.,* 1996), its insecticidal effect had never been reported on this particular mealybug species or any other from elsewhere. Among the homopterous insect pests, mealybugs and soft scales were reported to be insensitive to neem products (Schmutterer,1990). The results obtained here contradicts this report although the residue extracts from both neem seed kernel and *A. muricata* seed kernel were not insecticidal to the mealybug in this study. The non-effectiveness of aqueous seed residue extracts may be an indication that the active principles insecticidal to the mealybug were not present in the extracts. However, water and alcohol extracts of de-oiled neem seed kernel and aqueous seed kernel were reported to have demonstrated very good anti-feedant properties to unnamed insect species (Jhani Rani, 1984). Whether the active principles were lost from the residue extracts in the process of extracting the oil is not known. However, active principles like Azadirachtin and other active compounds were once obtained from neem seed kernels and some neem seed oil. Figure 12 shows 48-h dosage mortality regression line for crude extract from *A. indica* seed oil against adult female *R. invadens* while Figure 13 shows 48-h dosage mortality regression line for crude extract from *Annona muricata* seed oil against adult female *R. invadens.* Figure 12:

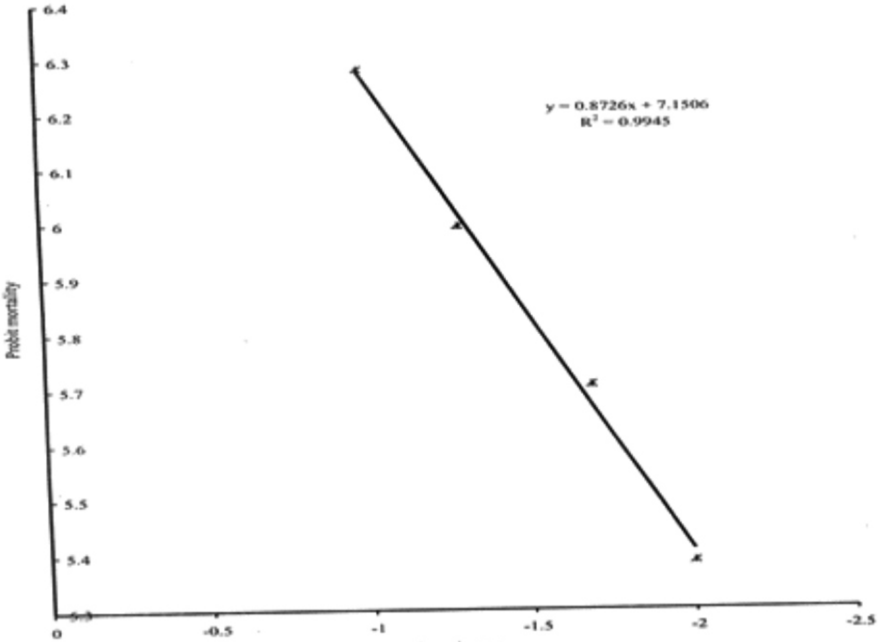


Figure: 12 **48-h dosage mortality regression line for crude extract from *A. indica* seed oil (contact toxixity test) against adult female *R. invadens*. dosage in µg/insect**

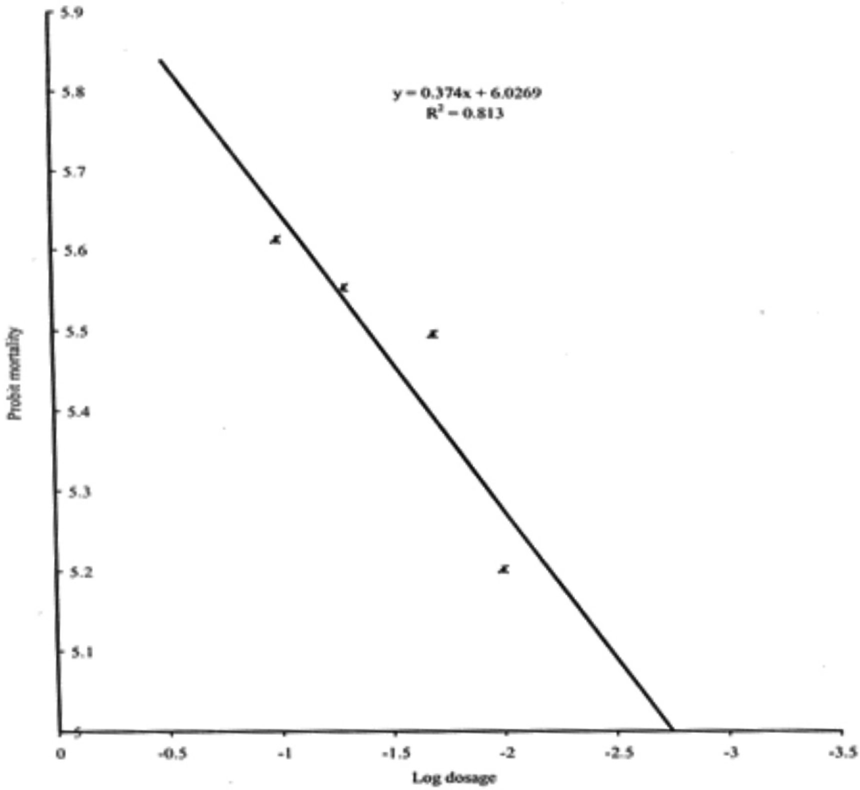


Figure: 13 **48-h dosage mortality regression line for crude extract from *Annona muricata* seed oil (contact toxicity test) against adult female *R. invadens*. dosage in μg/insect**

5.0. IN CONCLUSION

On the basis of research findings in this study, the following conclusions have been drawn:

- *R. invadens* successfully completed its life cycle on every candidate mango variety as the most preferred host of the mealybug.
- In terms of shorter pre-reproductive period and period of development, higher survival and number of crawlers produced, Local followed by Gesha and John varieties, proved more suitable as hosts to *R. invadens* than other varieties (Germer, Julie and Hindi).
- In this study, *R. invadens* population density increased with increase in number of leaves per flush and decreased with increase in leaf area among the mango varieties. This result may suggest that leaf area and number of leaves per flush could be an important variable that usually influence field population of *R. invadens* among other environmental factors.
- *R. invadens* population declined sharply from its uni-modal peak on its more suitable mango varieties (Gesha, Julie and Local) in the month of May (close to the beginning of rains) to the very low level in October probably because the joint forces of wind and rainfall characteristics of the zone.
- A similar windy rain condition could have probably accounted for similar sharp decline in the mealybug population from its bi-modal peaks observed on Gesha variety in the second year.
- Joint contributions to variation in *R. invadens* population by six environmental factors were significantly higher ($p<0.05$) on Gesha variety (r^2=66.8%), Pittri (r^2=59.7%), *C. sinensis* (r^2=66.0%) and P. alba (r^2=53.6%) compared to those recorded on other host plants.
- This revealed that host plants had significant influence on the changes in the mealybug populations. It can also be concluded that wind, *G. tebygi*, rainfall and relative humidity were important factors among others that significantly ($p<0.05$) influenced the mealybug population on one host plant or the other.
- Rate of parasitism (mortality due to reproductive behavior of the parasitoid) was very low, being higher on mango varieties

(Dabsha, Germer and Hindi) with low infestation and less on those (Gesha, Julie and Local) with high infestation.

- In this study, all the bio-control agents were generally low in numbers and found to increase only when *R. invadens* populations peaked on different host plants.
- The absence or numbers of its bio-control agents especially the indigenous ones, may be due to their preferences for food sources since they are not specific in their mode of feeding.
- Crude extracts (*A.indica* seed oil; *A. muricata* seed oil; root-bark extracts of *A. senegalensis* and *Z. zanthoxyloides*; (Leaf, stem-bark, root-bark and seed of *T. vogelii* and seed extracts of *T. candida*) of plants proved insecticidal to *R. invadens* either as contact, systemic or fumigant toxicity (or poison). Mortalities caused by each effective crude extract increased with increase in concentrations.

On the basis of the conclusions drawn from the research findings the following recommendations are given:

- In view of very low parasitism of *R. invadens* by *G. tebygi*, high reduction in number of the parasitoid by the hyperparasitoids and low predation by its predators, an integrated pest management approach may be necessary for the control of the mealybug.
- Therefore, the present knowledge of its different host plants, field biology/population, and the effective plant extracts are essential for developing a timely control action against *R. invadens* in Nigeria.
- Those mango varieties (for example, Germer, Dabsha and Hindi) prone to low *R. invadens* infestation could be utilized in plantation instead of Gesha, Local and Julie with a high infestation.
- In terms of more effective contact mode of action and availability, A. indica seed oil, followed by *T. candida* seed, *T. vogelii* stem-bark and *A. senegalensis* root-bark extracts can be developed as botanical insecticides for the field control of *R. invadens*.
- Further monitoring of the field populations of both *R. invadens* and its bio-control agents needs to be undertaken in the Guinea Savanna zone in order to acquire more information that could assist in the long-term control of the mealybug pest.

6.0. ACKNOWLEDGMENTS

Most importantly, I give praise and honour to the Omnipotent, Omnipresent and Omniscient God who gave me wisdom, knowledge, understanding and kept my Family and I in good health through the name of His son Jesus Christ in the course of the Research and writing.

I want to sincerely thank the immediate past Vice Chancellor of Federal University of Lafia, Professor Muhammed Sanusi Liman for initiating my entrance into FULafia through sabbatical engagement in 2019. I am also truly grateful to the incumbent Vice Chancellor, Professor Shehu Abdul Rahman for granting me full employment with FULAFIA.

In the same vein, I want to place on records my gratitude to my first Head of Department Professor Victoria Pam, Professor and Professor Mrs. Kwong Ndung, Prof. Victor S. Dugga my in-law. I thank Prof. Rebecca Ape, Professor Zara Kwaghe, Prof. Idris A. Amali for his fatherly advice every time.

I also wish to sincerely express my deep love to my Dear wife, Dr. Comfort Ojoma Ukwela, a former senior Reporter with Concord Press of Nigeria, a former Senior Programme Producer, a News Caster all in the Nigerian Television Authority, Makurdi and acting Assistant Director and Head of Department of Television production with the NTA Television College, Jos and Presently Ag. Head of Department Theatre and Media Arts FULAFIA, for her moral, cheerful and financial support always and throughout this work; and to my Dear twin children, Treasure Ateko-Ojo Prince and Triumph Ojodu Princess Ukwela, I am very grateful for your invaluable contribution to my life.

My wonderful parents; Elder Josiah I. Ukwela, my mother Agnes I. Ukwela (nee Udalor) and step mother Mary O. Ukwela (nee Ochakwe) for their cares, my siblings for their great concerns. I also thank my siblings very specially for the brotherhood and prayers.

My profound gratitude goes to my Postgraduate teachers, especially Professor M. C. Eluwa of blessed memory, Professor F. K. Ewete, Professor T. Ikotun, Professor G. I. Atiri, Professor J. A. Odebiyi, Professor Anthony Youdeowei, Professor M. F. Ivbijaro, and Professor I. Fawole.

My highly valued colleagues , especially the Dean, Faculty of Agriculture, Professor Alhassan Usman and Associate Professor A. J. Ibrahim, Head, Department of Agronomy, both of Federal University Lafia. ; Professor E. J. Ekefan, Professor L. L. Bello, Professor Sam Baba Onoja, Professor M. O. Adeyemo, Professor (Mrs.) E. Amuta, Dr. Isaac Amuta, a one time Medical Director to University Clinic., Professor Rabo the present Vice-Chancellor to Federal University Wukari in Taraba State. Professor N. I. Odiaka, Associate Professor P. A. Shave, Professor S. Attah, Professor E. Attah in Kogi State University, Professor E. Achor, Professor Jerry Abenga, late Professor John Akoh, Professor P. Egwuma. Professor A. Onekutu, Professor F. S. Agbidye, Dr. E. E. Ekoja, Dr. I. TIME, Professor M. O. Obasi, Professor F. A. Ajayi.

My special gratitude goes to Professor Francis. S. Idachaba, the first Vice-Chancellor of Federal University of Agriculture, Makurdi now Joseph Sarwuan Tarka University, Makurdi of blessed memory who was instrumental to my employment to Federal University of Agriculture, Makurdi in 1990,Engr/Professor E. I. Kucha, Former Vice-Chancellor Joseph Sarwuan Tarka University, Makurdi, Professor A. R. Kimbir, Former Vice-Chancellor to Joseph Sarwuan Tarka University, Makurdi, Professor J. Rabo the present Vice-Chancellor Federal University, Wukari in Taraba State, Professor E. O. Ogunwolu of blessed memory, Former Deputy Vice-Chancellor and Acting Vice-Chancellor of Federal University of Agriculture, Makurdi I must not forget Professor A. O. Nwankiti, Former Dean of Postgraduate School, Professor John. A. Ayoade, Former Deputy Vice-Chancellor, Federal University of Agriculture, Makurdi of blessed Memory, Professor B. A. Kalu, Former Director of Research, Federal University of Agriculture, Makurdi, Professor J. A. Odebiyi, Former Vice-Chancellor to Achievers University, Professor Femi Akindele, a renowned BIOMETRICIAN, Professor A. R. Ajayi of blessed memory, Dr. P. Neuenschwander, Former Director IITA Plant Health Management Division Cotonou, Benin Republic, Professor F. C. Okafor.

Major contributors to my Research work; Professor M. C. Eluwa, Professor J. A. Odebiyi, Dr. P. Neuenschwander, Mr. James Imeh, Dr.

G. Goergen, Mr. P. O. Ekwuno and Mr. S. Onoja, Mrs. Zenabu Ukwela (nee Yakubu).
My Special Appreciation goes to my course Mates who maintained good relationship with me, especially, Mr. Joseph Annene, Mr. Kemi Okolo, Mr. Isaac Achor, Mr. Moses Adi, Professor Davidson Egirani, Professor Emmanuel Ajav and Pastor Osato Osagie.

On the basis of laboratory and Field Assistance, I wish to express my Profound gratitude to Dr. P. Neuenschwander, Former Director to IITA Health Management Division, for providing some necessary literature materials for the work and for granting me the opportunity to visit their Biocontrol Centre ; to Dr. G. Goergen, Curator Insect Museum, for the identification of the insect specimens sent to IITA Biocontrol Centre; to Mr. James Imeh, staff of Extension unit , Benue State Agricultural and Rural Development Authority, for identification of different varieties of mango in the location of survey and sampling, and for grafting work carried out; to Mr. P. O. Ekwuno, a plant Taxonomist formally with the Department of Forestry, Wild Life and Range Management, Federal University of Agriculture, Makurdi, for identification of most plant species considered for the work; to Technologists in the Departments of Crop Production and Animal Production both of the University of Agriculture, Makurdi their assistance in the preparation of various plant extracts used for this work; to members of technical staff in Food Chemistry Laboratory Department of Food Science and Technology, Federal University of Agriculture, Makurdi, for their assistance in the analysis for food nutrients. I also which to thank my Brother-in-Law, Elder Friday E. Dikko, an Educationist with Local Primary Education Board in Ibaji L. G. A. Kogi State, for providing seed material used in raising plant stands used for the extracts.

My immediate and past project and Research students from both the Department of Crop and Environmental Protection, Federal University of Agriculture, Makurdi and from Department of Biological Sciences, Benue State University, Makurdi, giving a total of forty eight (48) students.

My wonderful hardworking M.Sc. graduates, including Mr. D. A. Anda, Mr. Katunku, Mr. D. Yorkmun, Mrs. O. C. Ogah and Mr. T. T. Iyongo.

My highly respected Ph.D Graduates, most especially, Dr. A. A. Aku, Dr. B. I. Richard, Dr. E. I. Okrikata and Dr. A. O. Oladejo.

My Dear Brethren of the same household of Faith including: Engr. Friday O. Ukwela, Dr. Reuben O. Ukwela, Professor Joel Eriba, Professor Femi Agbede of blessed memory, Rev. Godwin Orah, Rev. Godwin Omata, Bishop John Ugbenyo, Bishop Crown Adebo, Bishop Uwodi, Dr. Abel Agbo, Rev. Sam O. Ukwela, Elder Peter Ukwela, Engr. Gideon U. Ukwela, Dr. (Mrs.) O. Adeyemo, Pastor T E. Jordan, Pastor Joel Ikani, Rev. B. Abuje, Engr Friday Ugbenyo, Sis. Angelina Egwuda, Bishop/Justice C. Bakare, Pastor Joe Acheje, Beloved Rosemary Achema, Pastor Mike Ikumenu, Pastor Emmanuel O. Ojima of blessed memory, Pastor Peter. Igwogwo, who all in one way or the order stood with me under God in the course of my life's journey. To all my friends and associates, too numerous to mention, I am forever grateful.

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