Ecology, Biology and Chemical Control of Cotton Mealybug
*Phenacoccus solenopsis* (Tinsley) on some Vegetable Crops,
Gezira State, Sudan

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B.Sc. (Honors) in Crop Protection, Faculty of Agricultural Sciences,
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Ecology, Biology and Chemical Control of Cotton Mealybug

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Date: January/ 2018.
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Date of Examination : 11 / 1 / 2018
DEDICATION

To my father, mother and brother.
To my husband Wyle Ali Elbadawi and my son Ali.
To all members of my extended family, friends and colleagues in
Agricultural Research Corporation (ARC).
Acknowledgments

First, praise to Allah on his uncountable grace and help. I am very grateful to my family and my husband for their patience and support during this study.

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Ecology, Biology and Chemical Control of Cotton Mealybug *Phenacoccus solenopsis* (Tinsley) on some Vegetable Crops, Gezira State, Sudan

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**Abstract**

The recent out-break of cotton mealybug (CMB), *Phenacoccus solenopsis* (Tinsley) on many crops belong to different families was making a real worry for farmers and researcher. Tomato and eggplant were attacked by this invasive pest. The objectives of this work were to study the biology, ecology and chemical control on tomato and eggplant. Laboratory and semi-field trials beside field surveys were conducted with consideration to the temperature and relative humidity (RH) during the period of the study. The results revealed that on tomato: the mean period for the first, second, third instar, pre-oviposition, oviposition and post-oviposition were 4.5±1.29, 6.6±2.07, 6.0±2.16, 3.2±1.31, 3.7±1.77, 2.9±1.12 respectively. The total life cycle was 26.9±9.72 days. On eggplant the period was 6.0±1.56, 9.5±2.87, 10.3±3.29, 3.0±0.9, 4.33±1.72, 2.66±0.85 respectively. The total life cycle was 35.79±11.22 days. The female of (CMB) was found to lay only one ovisack on both tomato and eggplant. The number of nymphs/ovisack ranged between 30-475 nymphs. During the winter season, the mean number of cotton mealybug (MCNMB) and the infestation level of cotton mealybug (ILCMB) were highest (20–100 insect/15cm), (80-100%) for tomato and eggplant respectively in March where the temperature was ranged between 25–35ºc and the (RH) 20–30 %, and lowest (0-10 insect/15cm ), (30–90 %) respectively in January where the temperature ranged between 20–25ºc and (RH) 30–40 %. While during the rainy season the (MNCMB) and (ILCMB) were highest (20–60 insect/15cm ), (60-100%) respectively from September to November where the temperature range between 10-20ºc and (RH) 40–60% and lowest (0-10 insect/15cm ), (5–80%) respectively on both tomato and eggplant in August where the temperature was 10 -30ºc  and RH 70-80%. The predators recorded attacking (CMB) were: *Exochomus nigromuculatus* and *Scymnus sp.* The insecticides treatments show that: Selecton at double and recommended dose was the best one of the tested insecticides followed by the Diazinon and Sinomat with mortality% after 72 hrs : (100% , 85%), (97% , 90%),and (82%, 82%) respectively. When the LD90 was optimized and compared with the recommended dose show that: the LD90 of Diazinon was the only one less than the recommended dose. So, the insecticides ( Diazinon, Sinomat, and Selecton ) were recommended to control CMB on vegetables using recommended dose after testing on large scale field experiments. Also, it can be concluded that: the (MNCMB) and (ILCMB) record higher levels when the temperature was high and the RH is low. All these results were discussed and compared with the previous studies.
Phenacoccus solenopsis (Tinsley)

بيئة وإحصائية والمكافحة الكيميائية لبق القطن الدقيق

على بعض محاصيل الخضر، ولاية الجزيرة، السودان

أمينة العبيد محمد العبيد

ملخص الدراسة

إن إفرازات حشرة بق القطن الدقيق Phenacoccus solenopsis (Tinsley) في السودان، ولايتا الجزيرة، وإيجادا على بعض محاصيل الخضر، ولاية الجزيرة، السودان، آمنت العبيذ محيده العبيذ المكافحة العملية والمكافحة الإحصائية للدقيقة، كما وقعت掩饰 درجات الحرارة والرطوبة أثناء فترة إجراء هذه التجارب لأخذها في الاعتبار. وقد أوضحت النتائج أن فترة كل من الحرارية الأولية، الثانوية، الثالثة، وفترة ما قبل وفاة البض، وفترة وفاة البض، وما بعد وفاة البض، وفترة وفاة جماعة الأنس مخلص الدراسة تتعلق بالطار وحالة للبكش البض أو لحالة للبكش البض، وحالة للبكش البض.

من النتائج:

1. حصة في أجراء الدراسة أن متوسط تعداد الحشرة ومتوسط الإصابة كان أعلى ما يكون في مارس 304–250 (100% في الكرة). حصة في أجراء الدراسة أن متوسط تعداد الحشرة ومتوسط الإصابة كان أعلى ما يكون في مارس 304–250 (100% في الكرة). في أخرى, يتم الانتهاء من التعدادات في الدراسة. في אחרת (240–100% في الكرة), (304–100% في الكرة) على التوالي على كل من الطماطم والباذنجان، حيث كانت درجات الحرارة 20–25 متداعية لحالة للبكش البض وحالة للبكش البض. في الأخرى (304–100% في الكرة) على التوالي على كل من الطماطم والباذنجان، حيث كانت درجات الحرارة 20–25 متداعية لحالة للبكش البض وحالة للبكش البض. في الأخرى (304–100% في الكرة) على التوالي على كل من الطماطم والباذنجان، حيث كانت درجات الحرارة 20–25 متداعية لحالة للبكش البض وحالة للبكش البض.

وقد كان مبيد السيلوكتون الأكثر كفاءة لمكافحة بق القطن الدقيق، بليها الديازينون ثم الساينويثون بعد ضبط جرعة الأول LD90 = 0.3 ملم وعند ابتناء الديازينون. وعليه توسيع الدراسة باستخدام المبيدات الثلاث لمكافحة بق القطن الدقيق بعد إجراء التجارب على ابتناء الديازينون. وعليه توسيع الدراسة باستخدام المبيدات الثلاث لمكافحة بق القطن الدقيق بعد إجراء التجارب على ابتناء الديازينون. وعليه توسيع الدراسة باستخدام المبيدات الثلاث لمكافحة بق القطن الدقيق بعد إجراء التجارب على ابتناء الديازينون.
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CHAPTER ONE
INTRODUCTION

The recent out-break and flare-up of cotton mealybug (CMB) *Phenacoccus solenopsis* (Tinsley) on many crops belong to different families was making a real worry for both farmers and researchers. Tomato, *Lycopersicone esculentum* (Mill) and eggplant, *Solanum melongena* (Solanaceae) which are the main source of important vitamins, the most vegetable crops severely attacked by this invasive insect pest (Ibrahim 2007; Abd El-Ghany, 2011). A survey made in the Gezira and Khartoum states showed at least 26 host plant species belonging to 16 plant families were infested with CMB, reported from Gezira, Khartoum, Sennar, Gedarif, Kassala, White Nile and Blue Nile, Northern state and River Nile state, and the species was identified as *Phenacoccus solenopsis* (Tinsley) (Mohamed, 2015). The feeding habit of mealybug causes yellowing, defoliation, reduces plant growth and finally plant death at severe stages (Culik and Gullan, 2005).

Chemical control of (MB) is difficult (C.F Entsar, 2009), and no insecticides were recommended in Sudan to control CMB on tomato and eggplant. Based on this complex situation and the fact that, biological and ecological studies of any pest are essential to build successful control strategies, the objective of this study were as follow:

- Studies on the biology (i.e. developmental stages, pre-oviposition, oviposition, post-oviposition and life span) of (CMB) *Phenacoccus solenopsis* (Tinsley) on tomato and eggplant).

- Studies on the ecology of (CMB) (i.e. Effect of temperature and relative humidity on the mean and the infestation level of CMB on tomato and eggplant, and the natural enemies.

- Testing some insecticides from different groups already recommended as protocol for control tomato and eggplant insect pests to control CMB on tomato and eggplant.
CHAPTER TWO
LITERATURE REVIEW

2.1. Taxonomy and Nomenclature

2.1.1. Classification

Class: Insecta

Order: Hemiptera

Suborder: Sternorrhyncha

Super family: Coccoidea

Family: Pseudococcidae

Genus: Phenacoccus

Species: *Phenacoccus solenopsis* (Tinsley)

2.1.2. Taxonomy and Identification

Mealybugs belong to the super family Coccoidea and fall in the family Pseudococcidae which is the second largest family in the Coccoidae comprising 28% of the species after the family Diaspididae which comprises of 32% of the total described species (Miller *et al.*, 2005).

Recently, specimens on cotton, *Gossypium* spp in India with morphological characters that differed from *P. solenopsis* were referenced to as a new species, *Phenacoccus gossypiphilous* (Abbas *et al.*, 2005, 2008, 2009). The presence of morphological variations among specimens of *P. solenopsis* in different regions of India often led to misidentification of the mealybug species (Asha and Ramamurthy, 2008). However, because no type specimens were named, Hodgson *et al.*, (2008) considered the name to be a nomen nudum. Also, Hodgson *et al.*, (2008) concluded from a comprehensive
morphological study that there were no significant differences in specimens from the Indian subcontinent compared to those from the tropics; and thus, considered the name P. gossypiphilous to be a synonym of P. solenopsis.

*Phenacoccus manihoti* Matile-Ferrero is an example; this tropical species was accidentally introduced to Africa and became a very serious and rapidly spreading pest on cassava (Williams, 2004). Another example is *Rastrococcus spinvadens*, which was accidentally introduced from southern Asia to West Africa, where it devastated vast areas of fruit trees (Williams, 2004).

In Sudan Mohamed (2015) collected samples of mealybug from cotton and *Abutilon* spp and sent them to plant pest diagnostic center, Sacramento, CA, USA who confirmed the identification of the species as *Phenacoccus solenopsis* according to the description and taxonomic identification Key by Nagrare et al., (2011).

### 2.2. Distribution

The cotton mealybug (CMB) *P. solenopsis* (Tinsley) was initially reported as a pest of cotton in Texas, USA (Fuchs, 1991), followed by the Caribbean, an Ecuador report (Ben-Dov, 1994), Argentina (Granaradeillink, 2003), Brazil (Mark and Gullan 2005). Has also been reported as serious pest in China (Wang et al., 2009). *P. solenopsis* has been described as a serious and invasive pest of cotton in Pakistan and India (Hodgson et al., 2008).

Also the pest was distributed in Africa, Asia, North America and south America and oceanic regions including the Caribbean nations. Specimens from the various regions exhibit similar morphological characteristics (Hodgson et al., 2008). Also it has been reported from 35 locations of various ecological zones of the globe (Ben-Dov et al., 2009).

### 2.3. Description

Mealybugs are soft-bodied, sap-feeding insects with mouthparts adapted to piercing and sucking like aphids, whiteflies and mosquito pierces an avid hunter. They secrete a powdery, white wax covering over the body (Osborne, et al., 1994). *Pseudococcidae* constitute the second largest family of scale insect with more than 2000 described species and 290 genera (Ben-Dov, 2006). It has a wide range of
variation in morphological characters, biological adaptation and ecological adjustability (Hodgson, et al., 2008). This homopterous can inject a toxic-like compound into the plants, causing even greater damage than the typical visual feeding damage. Areas of heavy infestations are unsightly and look grainy or mealy because of overlapping bodies and heavy coating of white powdery wax, hence the name mealybugs. Besides the heavy waxy coating, another character that distinguishes mealybugs from other insects is the presence of marginal filaments or a fringe of waxy hair-like structures that may be wedge-shaped or spine-like; those found at the end of the abdomen resemble tails. Both the fringe hairs and the tails can be key characters for identification. (Cabi site, 2015).

2.3.1. Eggs

The eggs of (CMB) are deposited as white, cottony masses called ovisacks, on the leaves and stems of plants, giving the appearance of cotton spread on the plant. The glossy, light yellow eggs are oval and approximately 0.3mm long (Meyers, 1932). According to Tanwar et al., (2007) the eggs were 0.3-0.4 mm length and with width of 0.16 - 0.20 mm, with incubation period of 3-9 days. The eggs were minute, oval in shape and light yellow or whitish yellow in color (Kamariya, 2009).

2.3.2. Adult

2.3.2.1. Male

The adult male has no functional mouth parts and survives for 3-5 days (Tanwar et al., 2007). Also adult males are winged and thus capable of flying to new host plants for mating purpose (Anon., 2007). Male have 4 nymphal stages called first instars, second instar, pre pupa, pupa and adult stage (Hodgson et al., 2008). The wings in male are one a pair with 2 tail like appendages (Radadia et al., 2008). The adult male, pale brown in color with elongated body, the length and width observed were 0.99-1.1 mm and 0.25-0.26 mm respectively. One pair of mesothoracic wings was observed in male with wing expanse of 0.43mm (Dhawan and Saini, 2009). Males are quiet small, total-body length about 1.41mm; antennae about 2/3nds total-body length; body with few setae, all hair-like and fleshy; present on antennae and legs; length of antennae a little less than twice width of antennal segment; loculate pores mainly with 4, but occasionally 5, loculi. Abdomen with glandular pouches and
glandular pouch setae on segments VII and VIII. Penial sheath with a distinct constriction towards apex. Wings misshapen and length unknown, and can be distinguished from other flying insects by the two pairs of terminal filaments present at the end of their abdomens. (Hodgson et al., 2008).

2.3.2.2. Female

The female development consists of first (crawler) second and third instars and the adult. First instars are differentiated from the other stages by possessing six—segmented antennae, lack of circular, and quinguelocular pores on the head, thorax and abdomen. Second instar nymphs are distinguished by having 18 pairs of distinct cerci around the margin of the body, the lack of quinguelocular pore on the body and the claw with a distend identical. The third nymphal instar differs by having seven segmented antennae and a circular (Hodgson et al., 2008).

The adult female was oblong, light to dark yellow, wingless and yellowish body is largely covered by powdery white wax. Eighteen pairs of short waxy filaments existed around the body, the length and width observed were 4.1- 4.7mm and 2.8- 3.0mm respectively, (Dhawan and Saini, 2009).

2.4. Main Morphological Characters of Cotton mealybug

Adult females are with 9 segmented antennae, six pairs of transverse dark band located across the pro-to meta-thoracic. Waxy filaments extend from around the margin of the body with a pair of terminal filaments (Mohammed, 2015).

2.5. Biology

2.5.1. Eggs

The fecundity of mealybug was observed as 310-625 eggs/female with mean of 470 eggs/female. 98-239 nymph were observed in an ovisack. (Tanwar et al., 2007).

The eggs were carried an ovisack and mean 150-600 eggs were found in a single ovisack. The incubation period of the eggs was 6 to 9 days (Radadia et al., 2008). Also according to Akintola and Ande (2008), the egg was yellowish in color and about 150-600 eggs found in an ovisack, the incubation period was recorded 6-9 days.
2.5.2. Nymphs

The female nymphs resemble the adult females, while male nymphs are more elongated. Female nymphs have three instars. Males differ greatly; they have three instars and a pre-pupa stage. It is only the males that can produce a cottony-appearing cocoon and pupate. Male nymphs are narrower in appearance than females, and often occur in a loose cocoon (Anon., 2003).

There were three nymphal instars in female, while male had 4 nymphal instars. The 1st instar nymph was oblong, yellow, devoid of mealy scale with the length and width of 0.71-0.75 mm and 0.43-0.49 mm, respectively. Also, two caudal filaments on tip of the abdomen were noticed. The 1st instar nymph lasted for 4-6 days. The 2nd instar nymph was oblong, pale yellow and body lacked mealy waxy secretions. The length and width observed were 1.0-1.5 mm and 0.51-0.55 mm, respectively. Eyes were very clear at this stage, like red spot. Also, tip of the abdomen was protruded and has two caudal filaments. The 2nd nymphal instar lasted for 4-6 days for female and 4-5 days for male. The 3rd nymphal instar was dark yellow and oblong. White, puffy waxy coating over the dorsal surface was observed with light dark stripes on dorsal side. The length and width observed were 2.1-2.6 mm and 1.1-1.3 mm, respectively. Also, two caudal filaments on tip of the abdomen were noticed. The 3rd nymphal instar lasted for 5-7 days for female and 6-8 days for male (Dhawan and Sairi, 2009).

2.5.3. Adult stage

The development from crawler to adult ranges from 25 - 30 days, depending upon the temperature. This mealybug has been reported to be capable of surviving temperatures ranging from 0-45ºC, throughout the year (Sharma, 2007).

*P. solenopsis* has been shown to be sexually dimorphic, having short lived, winged males and longer-lived, wingless, females. It was found to reproduce sexually, producing youngs instead of laying eggs. The eggs are retained in the body until they are ready to hatch, a phenomenon known as ovoviviparity (Abbas et al., 2008). The location on the plant appears to be influenced by humidity. As Hodgson et al., (2008) concluded that *P. solenopsis* occurred more commonly on the roots, stems and foliage close to the soil line in dry climates compared to settling on the upper foliage of the plant in more humid areas.
Adult periods lasted for 13-17 days for female while, it was 1-2 days for male. The pre-oviposition, oviposition and post-oviposition period of the mealybug were 3-5 days, 8-9 days and 2-3 days, respectively. The fecundity of the pest was 270-340 young/female. The total life cycle of the female was 27-38 days (5 week), while it was 16-23 days in male (Dhawan and Saini, 2009). The first instar nymphs (crawlers) disperse to settle primarily on the leaves as well as the stems, leaf petioles, and bracts of fruiting cotton (Ben-Dov, 2010).

2.6. Damage

Mealybugs are sap-feeding insect that inflict losses to their host-plants in several ways (Osborne et al., 1994; Gullan and Kosztarab, 1997; Oetting, 2004; Williams, 2004; Watson and Kubiriba, 2005; Abbas et al., 2008). Some mealybug species transmit plant virus diseases while feeding; The feeding punctures facilitate infection by secondary diseases; Waxy mealybugs impair the aesthetic value of ornamental plants, presenting a serious threat to interior landscaping and greenhouse crops.

The feeding habits of mealybug cause yellowing, dieback and shedding of leaves. Reduced plant growth and in some caused death of plant (Culik and Gullan, 2005). This insect can be found in roots forming galls restricting water and nutrient absorption. They also remove sap from floral buttons and fruits, resulting in empty and dry berries (Sarta – Cecila et al., 2002, 2007). Besides honeydew, a sugary liquid is excreted by these insects on the leaves and serves as a medium for the growth of sooty mold fungus that reduce photosynthetic abilities (Saeed et al., 2007).

2.7. Ecology
As a result of *P. solenopsis* dispersal, reproductive and survival capacity, this invasive pest has the potential to damage or kill native plant species that could displaced by other more aggressive plant (Cabi site, 2015). Wang *et al.*, (2009) and Dhawan *et al.*, (2009) reported that *P. solenopsis* could infest regions within 17 provinces of China; inferred that meteorological factors influenced the presence and population size of the mealybug, humidity and rainfall had negative effect.

Lower temperature and higher humidity favored the buildup of the pest while increase in humidity was positively correlated with the increase in incidence of mealy bug at Pakistan (Anon., 2008). Brar *et al.*, (2009) revealed that the rain has great impact on the population of the pest. Dhawan and Saini (2009) found that weather conditions like temperature, relative humidity and rainfall showed positive effect on the insect biology and their incidence in field. Jeyakumar *et al.*, (2009) observed that the humidity favored the multiplication of the pest, but the intense rainfall adversely affects the spread and reduce the intensity.

### 2.8. Host Range

*P. solenopsis* has been recorded on members of 31 major plant genera in 13 families (Ben-Dov *et al.*, 2008). They had wide range of variation in morphological characters, biological adaptations and ecological adjustability (Hodgson *et al.*, 2008). (Arif *et al.*, 2009) reported that 154 species on which cotton mealybug was found incidentally or in low, medium or high intensity of mealybug in the agro-ecological conditions of Multan, Pakistan. It has been recorded from 154 plant species including field crops, vegetables, ornamentals, weed, bushes and trees (Arif *et al.*, 2009, Saini *et al.*, 2008).

Most of these belong to the family Malvaceae, Solanaceae, Asteraceae, Euphorbiaceae, Amaranthaceae and Cucurbitaceae, However, the economical damage has been observed on cotton, brinjal, okra, tomato, sesame, sunflower and china rose (Arif *et al.*, 2009). Abbas *et al.*, (2010) reported that *P. solenopsis* host plant more than 100 genera belonging to over 50 families.

### 2.9. Control
2.9.1. Cultural control and sanitary measures

Proper destroying and uprooting of infested plants, weeds as well as management of irrigation and fertilizers are the effective cultural methods to prevent the mealybug infestation (Anon., 2008).

It is important to prune or cut infested stems or branches from plants and destroy the infested plant material. Also stalks and crop residues in infested field sites should be removed and destroyed as such residues left in the field can harbor mealybugs, which can survive to invade the new crop. Attention should be given to the field borders for plants that can serve as an alternate host for the mealybug. Such plants should be removed to prevent the mealybugs from overwintering and infesting crops in the future. Trap plants may be planted that initially attract the mealybugs and can be targeted for control treatments to protect the primary crop. (Cabi site, 2015).

2.9.2. Physical or Mechanical Control

Small populations of *P. solenopsis* can be controlled by inspection of plants, removing loose bark where they might be difficult to observe and handpicking the specimens from newly-infested plants. Soap applications are often effective against targeted, small populations of the mealybug. (Cabi site, 2015).

2.9.3. Biological Control

The biological control is the beneficial action of the predators, parasitoids, pathogens and competitors in controlling pests and their damage, it has great value in sustaining environmental health, particularly through reductions of pesticide use (C.f. Entsar, 2009). Tanwar *et al.*, (2007) provided detailed information about invasive mealybugs found in India. They described the biology, mode of damage, and precautions and practices for invasive mealybug management. They were of the opinion that biological control was the most effective long-term solution to mealybug infestations because the parasitoids and predators are self perpetuating, persisting even when the host mealybug at low population densities.

2.9.3.1. Parasitoids
However, several parasitoids and predators have been documented to attack *P. solenopsis*. Three parasitic wasps (*Aenasius arizonensis*, *Cheiloneurus* sp., and *Aprostocetus sminutus*) were discovered attacking the solenopsis mealybug on cotton *Gossypium* spp. (Fuchs et al., 1991). Parasitism of this invasive mealybug on okra [*Abelmoschus esculentus*] increased within one season from its absence at germination to 89% parasitization rate at harvest (Sharma, 2007). In India, an unidentified species of the solitary endoparasitoid, *Aenasius* sp., was reported to attack *P. solenopsis* (Sharma, 2007; Tanwar et al., 2008). The parasitoid, *Aenasius* sp., was documented to parasitize 10-45% of the mealybugs on cotton and 5-65% of those were on alternate hosts. *Paranathrix tachikawai* was recorded parasitizing 30-39% of the mealybugs on cotton in India. Also, the parasitoid *Promuscedeau fasciati* produced 30-80% parasitism rate in nature and is a potential candidate to incorporate into a management strategy for the mealybug pest (Bambawali, 2008).

Hayat (2009) described a new species of parasitoid, *Aenasius bambawalei*, associated with *P. solenopsis*, which has been documented as a very effective candidate for biological control. This parasitoid was found parasitizing cotton mealybugs on several plants (Muniappan, 2009) and reported to parasitize up to 72% of the *P. solenopsis* populations infesting cotton plants grown in some districts in India (Muniappan, 2009; PalaRam et al., 2009). However a hyperparasitoid, *Promuscedeau fasciati*ventris, was found to attack *A. bambawalei*, which potentially may reduce the efficiency of this parasitoid. Parasitized specimens of the cotton mealybug cease feeding and their exoskeletons turn into reddish-brown mummies (Pala Ram et al., 2009).

### 2.9.3.2. Predators

A number of predators contribute in mealybug control. Few specialize on mealybug whereas most are generalists that prey on any small, soft–bodied arthropods. For many of these natural enemies, there are no studies of their impact on mealybug population. The most well known predator is the mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant, (Coleoptera) which is native to Australia, but has been exported throughout the world. Both adults and larvae can predate on mealybugs. The larvae, to some extent, are mealybug mimics, possessing wax-like filaments similar to those of mealybugs. This ‘camouflage’ allows beetle larvae to forage without too much disturbance from mealybug-tending ants (Anon., 2007).
Most predators feed on the eggs or crawlers within the mealybug’s ovisac and reduce the number of mealybugs available to extract sap and weaken the plant. Other potential predators, such as the larvae of the lacewing, *Chrysoperla carnea*, were found to consume 30 mealybug eggs daily in developmental laboratory tests (Rabinder *et al.*, 2008).

### 2.9.3.3. Pathogens

Kulkarni and Mote (2003) reported that the *Verticillium lecanii* at 2, 3, 4, 5, and 6 g/lit of water was effective for the control of mealybug. According to Ujjan and Saleem (2007), *Metarrhizium anisopliae* is able to infect the adult mealybug within 2 days and show 90% mortality.

*M. anisopliae* 2000 ML/ha was found very effective to control the pest at Rahuri (Maharashtra) (Anon., 2008). *Verticillium lecanii* (Zimmemann), *Metarrhizium anisopliae*. Metschnikow and *Beauveria bassiana* (vuillemin) are most effective fungal pathogens of the pest (Tanwar *et al.*, 2007 and Radadia *et al.*, 2008).

### 2.9.4. Chemical Control

An early chemical control effort against *P. solenopsis* in the USA proved unsatisfactory (Fuchs *et al.*, 1991). Although the problem of *P. solenopsis* on cotton in Pakistan is recent, some work on its chemical control has been done. Zaka *et al.*, (2006) worked on the relative efficacy of different pesticides against cotton mealybug in Pakistan. They concluded that Methomyl, Triazophos and Methamidophos were the most effective pesticides against CMB, followed by Imidacloprid. Tanwar *et al.*, (2007) reported that a number of pesticides were tested against these pests: Lamdacyhalothrin (Boxer, 2.5 EC), Bifenthrin (Talstar, 10 EC), Profenophos (Craker, 50EC), Imidacloprid (Crown, 200SL), (Alarm, 1.8EC), (Proclaim, 19EC), Chlorpyriphos Dorsban, 40EC), Mathidathion (Supracide, 40EC), (Advantage, 20 EC), Acetameprid (Rani, 20EC) were tested in a laboratory bioassay and then in the field. After 72 hours Profenophos was most effective, followed by Supracide and Talstar (with mortality rates of 68.34%, 65.83% and 48.23% respectively). However, after 168 hours Supracide superceded Profenophos, causing 94.7% and 92.87% mortality rate respectively (Arif *et al.*, 2008). Similar results were reported by Saeed *et al.*, (2007), who tested insecticides of different groups against CMB in the laboratory as well as in the field in Pakistan. In the laboratory, using the leaf dip method, Bifenthrin, Profenofos and Chlorpyrifos proved to be the best insecticides for
mealybug control, based on the LC$_{90}$. In field conditions, the recommended application rates of Methomyl, Profenofos and Chlorpyrifos provided the best control; lethal time studies proved their efficiency for timely control of this sporadic pest.

Profenofos, Chlorpyrifos, Methomyl and Bifenthrin, provided satisfactory control of CMB (Saeed et al., 2007). Dhawan et al., (2008) found Emmamectin Benzoate most effective against CMB in abioassay test, followed by chlorantroniliprole, then pyridalyl, nuvaluron, quinalphos, thiodicarb, flubendiamide, acephate and chlorpyrifos, with endosulfan being the least effective. Profenophos, Thiodicarb, Quinalphos, and Acephate gave more than 90% kill of the pest using the recommended doses and 200 litres of water as spray material (Saini and Ram, 2008).

2.9.5. Botanical Products

Successful efforts were done by (Nagrare et al., 2009) using Azadirachta indica (Neem) tree seed extraction equally effective in pest control, industries and medicines and for others. In addition, tobacco, huing, dhatoora and Meethaneem (Melia azadirachta) is also considered as non-hazardous, economical and safest having no lethal effects with a high rate of efficiency against a variety of pest insects as described by (Narwal et al., 2009).

2.9.6. Integrated pest management (IPM)

A management strategy to control P. solenopsis in India that incorporates cultural, mechanical, biological and chemical control factors has recently been developed (Tanwar et al., 2007). Achievement of effective pest management is the ultimate objective of all basic studies of a new agricultural pest. Integrated Pest Management (IPM), of all the management strategies available, is the most desirable because it uses a system approach to reduce pest damage to tolerable levels through a variety of techniques, and only uses chemical pesticides when necessary and appropriate (Emden, 2002). This concept has further developed into bio-intensive IPM, in which living organisms such as predators, parasites, fungi, resistant varieties, trap crops etc. are the main components of the program (Dufour, 2001; Emden, 2002).

Chapter Three
Material and methods

3.1. Biological studies

3.1.1. Number of ovisack/female

This study was conducted at Entomology Section, Crop Protection Research Center, Agriculture Research Corporation, Wad Medani, Sudan during January–March 2016. Special leaf or plant cage were used. These cages made from disposable plastic containers, in each cage a leaf of tomato or eggplant was placed with one adult female. This was replicated fifteen times. Cages were observed daily for egg laying during the life span of the adult female.

The same individual adult in the cage was shift to another leaf in the same leaf (eggplant) or branch (tomato) cage, daily after counting the ovisack, eggs or nymph observed. Soft camel hair brush and the eye lance of binocular microscope (5x) were used in counting the neonate of the mealybug. First the adult was removed gently by the brush to a new leaf and the a counted individual of neonate were excluded gently by using the Bruch and the magnifying lance. Number of ovisack observed and nymph or egg were recorded and subjected to analysis.

3.1.2. Number of eggs/ovisack

The number of eggs per ovisack for each insect was recorded using binocular microscope (5x) and replicated over one hundred times.

3.1.3. Incubation period of the eggs

Egg laid by each mealybug female was closely observed to determine the incubation period.

3.1.4. Period of nymphal instars

Five newly hatched crawlers of mealybug (first nymphal instar) from study 3.1.3 were enclosed in a separate leaf cage of tomato or eggplant with 20 replicates. The nymphal period was observed every 24hrs using a magnifying hand lens (5x).
The nymph was considered passing to another stage when a change in size, presence of exuvia or deposition of wax was observed.

3.1.5. Life span of adult female

The newly hatched crawlers were reared to the adult stage which determined by the sign, presence of exuvia or deposition of wax, then the total life span for the adult was monitored.

3.1.5.1. Pre-Oviposition period

The objective of this study was to determine the period taken by the adult stage to the first appearance of ovisack out of the ovipositor or from last instar to appearance of first ovisack.

3.1.5.2. Oviposition period

To determine the oviposition period, the days were recorded from the first appearance of ovisack up to be disappeared, or from the appearance of new emerge nymphal instar up to the last one.

3.1.5.3. Post-Oviposition period

This experiment aimed to determine the time taken from end of oviposition to the death of the adult female of mealybug.

3.2. Ecological Studies

3.2.1. Infestation level of cotton mealybug (ILCMB)

Twenty plants of each crop were randomly selected in each plot for the infestation level using the following formula:

\[
\text{Infestation percentage} = \left( \frac{\text{Number of infested plant}}{\text{Total number of plant examined}} \right) \times 100
\]
3.2.2. Mean number of cotton mealybug (MNCMB)

In this experiment monitoring was carried during January–March and August-December 2016 to estimate the (MNCMB) were conducted on untreated plots of tomato and eggplant fields.

Twenty plants of each crop were randomly selected in each plot and examined. In each plant 15 cm of the stem or the branch (medium) were examined and number of mealybug were counted and recorded.

3.2.3. Natural enemies

Monitoring for natural enemies was carried on the same way of (3.2.1) but here natural enemies observed were recorded, collected and sent to Taxonomic Unit of ARC to be identified.

3.2.4. Meteorological data

Temperature and relative humidity (RH) during the period study was supplied by ARC, Meteorological Station, Wad Medani, Sudan.

3.2.5. Control

The insecticides under test were preferred to be within the insecticides already recommended to control other insect pest on the same crop. The selected insecticides were shown in Table (1).
<table>
<thead>
<tr>
<th>Insecticide tested</th>
<th>Group</th>
<th>Trade name</th>
<th>Properties</th>
<th>Uses</th>
<th>Mode of action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diazinon 60% EC</td>
<td>Organophosphorus</td>
<td>Diazol, Dianozyl, Dianon</td>
<td>Non-systemic insecticides and acaricide with contact stomach, And respiratory action.</td>
<td>Control of sucking and chewing insect and mites.</td>
<td>Biochemistry: cholinesterase inhibitor Formulation type CS, EC. Phytotoxicity: Non hytotoxicity when used as directed.</td>
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<tr>
<td>Sinomat 80% SE</td>
<td>Organophosphorus</td>
<td>Folimat</td>
<td>Systemic insecticides and stomach action</td>
<td>Control of spider mite, Aphid, beetles. Thrips and scale insect.</td>
<td>Biochemistry: cholinesterase inhibitor Formulation type SE, EC, AE, UL.</td>
</tr>
<tr>
<td>Selecton EC 50%</td>
<td>Organophosphorus</td>
<td>curacron</td>
<td>Non-systemic insecticide and stomach action.</td>
<td>Control of insects (particularly Lepidoptera) and mites on cotton</td>
<td>cholinesterase inhibitor</td>
</tr>
<tr>
<td>Imidor 35% SE</td>
<td>Imidaclorpid</td>
<td>imidor</td>
<td>Systemic insecticide</td>
<td>Control of sucking insect</td>
<td>cholinesterase inhibitor</td>
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</table>
3.2.5.1. Preparation and application of selected insecticides

The experiment was conducted in both laboratory (Petri dishes) and semi-field (Cage). Spraying solution was prepared according to the recommended dose. Calibration of hand sprayer was done before application.

3.2.5.2. Bioassay Trial

3.2.5.2.1. Laboratory trials

Plant leaf was dipped in specific insecticides solution at certain concentrations. After 15min the treated plant leaves were transferred to the Petri dish with insect under study. The plant leaf containers were treated first then the insect released. The mortality was recorded daily for 72hours. Then the data were organized and subjected to statistical analysis.

3.2.5.2.2. Semi-field or cage trials

To prevent cross contamination in laboratory, spraying was done outside. After calibration of the hand sprayer, then the water (control) treatment was applied and then the other treatment with the selected insecticides on the pot grown tomato or eggplant. A number of insect were released first then both of the insect and plant were treated in the next day with different dose of the insecticides with four replicates. For both laboratory and semi-field trials, both temperature and RH% were recorded during the study period and considered during the analysis of data. Records of insect mortality started 24, 48 and 72 hours after treatments were applied. Every day the number of dead insects in previous 24, 48 and 72 hours were recorded. The data were subjected to statistical analysis. Four doses were used for each of the selected insecticides with four replicates on eggplant.
3.2.5.3. Data collection and analysis

Cumulative mortality at the end of the experiment was calculated and analyzed using analysis of variance (ANOVA). Duncan’s multiple range test (DMRT) were used to determine significant differences between the means. Data mortality were transformed as needed using Abbott's formula and subjected to probit analysis SPSS soft word. The lethal dose for 50% (LD$_{50}$) and lethal dose for 90% (LD$_{90}$) of the tested sample were detected using the probit analysis SPSS.

Mortality of cotton mealybug were taken every 24, 48 and 72 hr for each treatment. The mortality corrected by Abbott's.

\[
\text{Corrected mortality} = \frac{Treated\ %\ mortality - Control\ %\ mortality}{100 - Control\ %\ mortality} \times 100
\]

More over the LD$_{90}$ for mealybug was optimized for the insecticides under study and compared with recommended dose for other insect pests on tomato and eggplant.
CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. Biological studies

4.1.1. Number of ovisacks/female

Table (2) shows the number of ovisacks laid by each of the 20 females. No eggs were seen but only one ovisack/female full of nymphal instar. No available literature about the number of ovisack/female. But many authors reported on the number of eggs/female and the fecundity of mealybug and found that 310-625 eggs/female with mean of 470 eggs/female. However, 98-239 nymphs were observed in an ovisack (Tanwar et al., 2007). The eggs were laid in an ovisack and an mean of 150-600 eggs were found in a single ovisack. The incubation period of the eggs was 6 to 9 days (Radadia et al., 2008). About 150-600 eggs found in an ovisack, the incubation period was recorded 6-9 days (Kintola and Ande, 2008). Considering the reports of these authors and the mean of total number/female beside the mean of egg/ovisack, the mean number of ovisack/female can be computed as 1-2 ovisack/female which agreed with the result of this study which found only one ovisack/female.
Table (2) Number of ovisacks laid by each female of *P. solenopsis* on tomato and eggplant

<table>
<thead>
<tr>
<th>Female experimented</th>
<th>Number of ovisack laid by each</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20</strong></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>
4.1.2. **Number of eggs/ovisack**

No eggs were seen during this study. Only one ovisack/female was recorded full of nymph instar that were considered as the number of nymph/ovisack. **Table (3)** shows the number of nymphs/ovisack on both host plant i.e Tomato and Eggplant. Among the 130 ovisack tested, the highest mean number of nymphs/ovisack was found to be 459 nymphs/ovisack, while the lowest mean number was 70 nymphs/ovisack with an average of 167 nymph/ovisack i.e. 21715 nymph observed in 130 ovisack. Also as shown in table (2) that the female observed to lay only one ovisack, and Table (3) showed that the mean, lowest and highest mean number/ovisack was 70, 459 and 167 respectively, also this Table illustrated that more than 38% of the examined ovisack contain 100–200 nymphs, while 6% of them contain 400–500 nymph. That means the nymphs laying capacity of this species was high i.e. 100-200 or 400-600 nymphs/ovisack when compared with the previous results obtained by Radadia *et al.*, (2008) who found the mean 150-600 egg/ovisack and the total number of egg/female 310-625 with mean of 470 eggs/female by Tanwar *et al.*, (2007).
Table (3) Mean number of nympha/ovisack of cotton mealybug *P. solenopsis* on tomato and eggplant

<table>
<thead>
<tr>
<th>Number of nympha/ovisack</th>
<th>ovisack</th>
<th>Total number of nympha</th>
<th>Mean number of nympha/ovisack</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>0 - 100</td>
<td>43</td>
<td>33.1</td>
<td>3038</td>
</tr>
<tr>
<td>101- 200</td>
<td>50</td>
<td>38.5</td>
<td>7252</td>
</tr>
<tr>
<td>201 – 300</td>
<td>20</td>
<td>15.4</td>
<td>4658</td>
</tr>
<tr>
<td>301 – 400</td>
<td>9</td>
<td>6.9</td>
<td>3091</td>
</tr>
<tr>
<td>401 – 500</td>
<td>8</td>
<td>6.1</td>
<td>3676</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>130</td>
<td>100</td>
<td>21715</td>
</tr>
</tbody>
</table>

Average nympha/ovisack 167
### 4.1.3. Period of nymphal instars on tomato and eggplant

Table (4) and appendices (2,3,4,5 and 6) show that, the CMB have only three nymphal instars. The periods (days) taken by the first, second and third nymphal instar were (4.5±1.29, 6.0±1.56), (6.6±2.07, 9.5±2.87) and (6.0±2.16, 10.3±3.29) on tomato and eggplant respectively. Also these appendices and Table (4) show the pre oviposition, oviposition, post oviposition and total life cycle as (3.2±1.31, 3±0.90), (3.7±1.77, 4.33±1.72), (2.9±1.12, 2.66±0.85) and (26.9±9.97, 35.79±11.22) on tomato and eggplant respectively. The time required for growth and development was longer on eggplant compared to tomato. However similar result were shown by Sharma, (2007) who found that the period of development from crawler to adult stage is approximately 25-30 days, depending on the weather and temperature. Mean development period were 4.9±1.4, 4.5±0.6 and 5.9±1.1 days respectively for the first, second and third instars of female and 15.3±1 days mean development from crawler to adult stage (Mohammed, 2015).

While the same trend was observed for the pre, post and oviposition period but with low rate. The results of this study here were similar to what was obtained by Dhawan and Saini, (2009), who were found that the female of CMB have three nymphal instars, the first instar nymph lasted for 4-6 days, the second was also 4-6 days and the third instar nymph lasted 5-7 days and the adult female period lasted for 13-17 days, while the pre oviposition, oviposition and post oviposition were 3-5, 8-9 and 2-3 days, respectively.
Table (4) Period (days) required for growth and development for various stages of *P. solenopsis* on tomato and eggplant

<table>
<thead>
<tr>
<th>Stage</th>
<th>Days Mean± SD</th>
<th>Tomato</th>
<th>Eggplant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomatoes &amp; Eggplants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First instar</td>
<td>4.5±1.29</td>
<td>6.0±1.56</td>
<td></td>
</tr>
<tr>
<td>Second instar</td>
<td>6.6±2.07</td>
<td>9.5±2.87</td>
<td></td>
</tr>
<tr>
<td>Third instar</td>
<td>6.0±2.16</td>
<td>10.3±3.29</td>
<td></td>
</tr>
<tr>
<td>Pre oviposition</td>
<td>3.2±1.31</td>
<td>3.0±0.90</td>
<td></td>
</tr>
<tr>
<td>Oviposition</td>
<td>3.7±1.77</td>
<td>4.33±1.72</td>
<td></td>
</tr>
<tr>
<td>Post oviposition</td>
<td>2.9±1.12</td>
<td>2.66±0.85</td>
<td></td>
</tr>
<tr>
<td>Total life cycle</td>
<td>26.9±9.72</td>
<td>35.79±11.21</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Ecological studies

4.2.1. Relationship between temperature, mean number of cotton mealybug (MNCMB) and infestation level of cotton mealybug (ILCMB) on winter season 2016.

4.2.1.1. On Tomato

Figure (1) shows that the mean number of cotton mealybug (MNCMB) and the infestation level (ILCMB) were low (0-10 insect/15cm) and (50-90%), respectively during January where the mean temperature ranged between 20–25°c and began to increase during March (40-100 insect/15cm) and (80-100%), respectively where the mean temperature ranged between 25-35°c.

4.2.1.2. On Eggplant

Also figure (2) shows the same trend. (MNCMB) and (ILCMB) were low (0-10 insect/15cm) and (30-45%), respectively during January where the mean temperature range between 20-25°c and began to increase during March to reach the peak (20-30 insect/15cm) and (80-100%), respectively at the late of the month where the mean temperature 25-35°c and began to decline in April.

4.2.2 Relationship between temperature, mean number of cotton mealybug (MNCMB) and infestation level of cotton mealybug (ILCMB) on *P. solenopesis*, rainy season 2016

4.2.2.1. On tomato:

Figure (3) shows that the (MNCMB) and (ILCMB) were low (0-10 insect/15cm) and (60-80%), respectively on tomato during Augusts where the temperature ranged between 25-30°c and began to increase during September and reach the peak (40-60 insect/15cm) and (80-100%), respectively during late October and mid November where the temperature ranged between 35-40°c.

4.2.2.2. On eggplant

Figure (4) Shows the same trend (MNCMB) and (ILCMB) on eggplant i.e. low (0-5 insect/15cm) and (5%), respectively in August where the temperature ranged between 10-20°c and high (20-40 insect/15cm) and (60-100%) respectively in October and November where the temperature ranged between 10 – 20°c.
Figure (1) Relationship between average temperature, mean number of CMB and the infestation level of CMB on tomato, winter season 2016

Figure (2) Relationship between average temperature, mean number of CMB and infestation level of CMB on eggplant, winter season 2016
Figure (3) Relationship between max temperature, mean number of CMB and infestation level of CMB on tomato, rainy season 2016.

Figure (4) Relationship between range of temperature, mean number of CMB and infestation level of CMB on eggplant, rainy season 2016.
4.2.3. Effects of relative humidity on mean number of cotton mealybug (MNCMB) and infestation level of cotton mealybug (ILCMB) winter season 2016

Figure (5 and 6) show that the relative humidity (RH) have negative effect on both (MNCMB) and (ILCMB) on both tomato and eggplant.

4.2.3.1. On tomato:

Figure (5) shows that the (MNCMB) and (ILCMB) were high (80-90 insect/15cm), and (80-90%) respectively in March, where the (RH) ranged between 20-30% and low (0-10 insect/15cm) and (60-70%) respectively in January, where the (RH) ranged between 30-40%.

4.2.3.2. On eggplant:

As shown in Figure (6) the same trend of (MNCMB) and (ILCMB) was observed on eggplant. (MNCMB) and (ILCMB) were low (0-10 insect/15cm) and (30-40%) respectively in January, where the (RH) ranged between 30-40% and high (20-30 insects/15cm) and (90-100%) respectively in March where (RH) ranged between 20-25%.

4.2.4. Effects of relative humidity on mean number of cotton mealybug (MNCMB) and infestation level of cotton mealybug (ILCMB) rainy season 2016.

4.2.4.1. On tomato

Figure (7) shows that the (MNCMB) and (ILCMB) were low (0-5 insect/15cm) and (70%) during August where the (RH) ranged between (70-80%) And high (40-50 insect/15cm) and (80 -100%) during October and November where the (RH) ranged between 40-60%.

4.2.4.2. On eggplant

Figure (8) shows that, the (MNCMB) and (ILCMB) on eggplant have the same trend as on tomato. The (ANCMB) and (ILCMB) were low( 0-5 insect/15cm) and (0-5%) respectively in August where the (RH) was 80% and high (20-30 insect/15cm ) and (60-80%) respectively during October and November where the (RH) ranged between (40-60%). It can be concluded that: The (MNCMB) and (ILCMB) can reach the peak on tomato and eggplant during March, October and November where the temperature was high (30-40ºc ) and the RH is low (20-30%),
and low during January and August where the temperature was low (20-25ºc) and the RH was high (60-80%). This results does not agreed with many findings reported by many authors from different places, e.g. Reports from Pakistan revealed that lower temperature and higher humidity favored the buildup of the pest while increase in humidity was positively correlated with the increase in incidence of mealy bug at Pakistan (anonymous, 2008b). Brar et al., (2009) revealed that the rain has great impact on the population of the pest. Dhawan and Saini (2009) found that weather conditions like temperature, relative humidity and rainfall showed positive effect on the insect biology and their incidence in field. Jeyakumar et al., (2009) observed that the humidity favored the multiplication of the pest, but the intense rainfall adversely affects the spread and reduce the intensity.

4.3.5. Natural enemies

Predators recorded attacking CMB and recognized by Taxonomic Unit of ARC, Wad Medani Sudan, were Exochomus nigromululatus. Scymnus sp. (Coccinellidea).
Figure (5) Effect of RH on mean number of CMB and infestation level of CMB on tomato, winter season 2016

Figure (6) Effect of RH on mean number of CMB and infestation level of CMB on eggplant, winter season 2016
Figure (7) Effect of RH on mean number of CMB and infestation level on tomato, rainy season 2016

Figure (8) Effect of RH on mean number and infestation level of CMB on eggplant, rainy season 2016
Plate(7): Larvea of *scymnus sp*
4.3. Chemical control

4.3.1. Semi-field or cage trials

All the insecticides selected for this experiment were already recommended to control sucking insects (Jassed, Aphid and Whitefly) on tomato and eggplant

Effect of different doses of insecticides on CMB on eggplant

Table (5a) shows that the highest mortality% of CMB was obtained when double dose of Diazinon was applied i.e. 97% which was not significantly different from the recommended dose 90% after 72hr. Even after 48hr the two doses showed the same effect with significant difference 95% and 82% respectively. Hence, the recommended dose of Diazinon for other insect pest can be used successfully and effectively to control CMB on eggplant.

Table (5b) also shows that when Sinomat was applied with double recommended dose compared to the recommended one, the highest mortality% of CMB was obtained after 72 hr with no significant differences between the two doses, i.e. 82% and 82%. Even after 48 hrs the two doses show the same effect with no significant difference, i.e 72% and 70% respectively. Hence, the recommended dose of Sinomat for other sucking insects pest can be used successfully and effectively to control CMB on eggplant.

Table (5c) shows significant differences between double and recommended dose of Selecton after 72 hr i.e. 100% and 85% respectively.

Table (5d) shows that the least mortality% of CMB after 72 hr or 48 hr (37% , 47% or 37%,40%), respectively were obtained when double and recommended dose of Imidor were applied to control CMB on eggplant.

It can be concluded that the best insecticide to be used to control CMB on eggplant and tomato at its recommended dose was Selecton followed by Diazinon and Sinomat. While Imidor was the least effective one of the four tested recommended insecticides.
Table (5a): Effect of different doses of Diazinon on the mortality% of (CMB) on eggplant

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Mortality%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hrs</td>
</tr>
<tr>
<td>1500</td>
<td>87.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>750</td>
<td>70.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>375</td>
<td>45.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>187</td>
<td>50.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>0.0&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>SE±</td>
<td>4.92</td>
</tr>
<tr>
<td>CV %</td>
<td>19.47</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same latter(s) are not significantly different according to Duncan Multiple Range Test (DMRT) at P ≤ 0.05.

Table (5b): Effect of different doses of Sinomat on the mortality% of CMB) on eggplant

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Mortality%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hrs</td>
</tr>
<tr>
<td>200</td>
<td>55.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>100</td>
<td>50.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>37.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>25</td>
<td>30.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>0.00&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>SE±</td>
<td>3.87</td>
</tr>
<tr>
<td>CV %</td>
<td>22.45</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same latter(s) are not significantly different according to Duncan Multiple Range Test (DMRT) at P ≤ 0.05.
Table (5c): Effect of different doses of Selecton on the mortality % of (CMB) on eggplant

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Mortality %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hrs</td>
</tr>
<tr>
<td>1152</td>
<td>92.5 a</td>
</tr>
<tr>
<td>576</td>
<td>82.5 a</td>
</tr>
<tr>
<td>288</td>
<td>62.5 b</td>
</tr>
<tr>
<td>144</td>
<td>65.5 b</td>
</tr>
<tr>
<td>Control</td>
<td>0.00 c</td>
</tr>
<tr>
<td>SE±</td>
<td>4.80</td>
</tr>
<tr>
<td>CV %</td>
<td>15.90</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same latter(s) are not significantly different according to Duncan Multiple Range Test (DMRT) at P ≤ 0.05.

Table (5d): Effect of different doses of Imidor on the mortality % of (CMB) on eggplant

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Mortality %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hrs</td>
</tr>
<tr>
<td>400</td>
<td>30.0 a</td>
</tr>
<tr>
<td>200</td>
<td>22.5 ab</td>
</tr>
<tr>
<td>100</td>
<td>27.5 a</td>
</tr>
<tr>
<td>50</td>
<td>17.5 b</td>
</tr>
<tr>
<td>Control</td>
<td>0.00 c</td>
</tr>
<tr>
<td>SE±</td>
<td>2.78</td>
</tr>
<tr>
<td>CV %</td>
<td>28.48</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same latter(s) are not significantly different according to Duncan Multiple Range Test (DMRT) at p ≤ 0.05.
4.3.2. Dose optimization and laboratory trial

Table (6,a,b,c,) and Appendices (11a,b,c,d,) show that, when the LD\(_{90}\) of the three effective insecticides (Diazinon, Sinomat and Selecton) were optimized i.e tested in comparison with their recommended dose, it was found that: Only the LD\(_{90}\) of the Diazinon was less than its recommended dose (722 ppm and 750 ppm), respectively to control CMB. While the LD\(_{90}\) of the other tested insecticides were higher than their recommended dose. That meant: in addition to the recommendation that Diazinon, Sinomat and Selecton can be used successfully to control the CMB together with other insect pest, but Diazinon can be used successfully with less than the recommended dose to control CMB in a case of absence of other insect pest. These results agreed with Arif et al., (2008) when he tested Profenofos and evaluated it after 72 hours was most effective with mortality rate of 68.34\% and after 168 hours causing 94.7\% mortality rate, similar results were reported by Saeed et al., (2007) who tested insecticides of different groups against CMB in laboratory who found the Profenofos was the best insecticides for mealybug control based on LD\(_{50}\). (Saini and Ram (2008) found the profenofos acephate gave more than 90\% kill.
**Table (6a) Effect of different doses of Diazinon on the mortality% of cotton mealybug on eggplant compared with LD$_{90}$**

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Mortality %</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hrs</td>
<td>48 hrs</td>
<td>72 hrs</td>
</tr>
<tr>
<td>1500</td>
<td>87.5$^a$</td>
<td>95.0$^a$</td>
<td>97.5$^a$</td>
</tr>
<tr>
<td>750</td>
<td>70.0$^b$</td>
<td>82.5$^b$</td>
<td>90.0$^a$</td>
</tr>
<tr>
<td>375</td>
<td>45.0$^c$</td>
<td>60.0$^c$</td>
<td>87.5$^a$</td>
</tr>
<tr>
<td>187</td>
<td>50.0$^c$</td>
<td>60.0$^c$</td>
<td>70.0$^b$</td>
</tr>
<tr>
<td>722</td>
<td>65.0$^b$</td>
<td>75.0$^b$</td>
<td>85.0$^a$</td>
</tr>
<tr>
<td>Control</td>
<td>0.00$^d$</td>
<td>0.00$^d$</td>
<td>0.00$^c$</td>
</tr>
<tr>
<td>SE±</td>
<td>4.94</td>
<td>3.49</td>
<td>4.50</td>
</tr>
<tr>
<td>CV %</td>
<td>18.66</td>
<td>11.23</td>
<td>12.57</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same latter(s) are not significantly different according to Duncan Multiple Range Test (DMRT) at p ≤ 0.05.

**Table (6b) Effect of different doses of Sinomat on the mortality% of cotton mealybug on eggplant compared with LD$_{90}$**

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Mortality %</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hrs</td>
<td>48 hrs</td>
<td>72 hrs</td>
</tr>
<tr>
<td>200</td>
<td>55.0$^b$</td>
<td>72.5$^{ab}$</td>
<td>82.5$^b$</td>
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<td>100</td>
<td>50.0$^b$</td>
<td>70.0$^{ab}$</td>
<td>82.5$^b$</td>
</tr>
<tr>
<td>50</td>
<td>37.5$^c$</td>
<td>62.5$^b$</td>
<td>75.0$^b$</td>
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<tr>
<td>25</td>
<td>30.0$^c$</td>
<td>37.5$^c$</td>
<td>57.5$^c$</td>
</tr>
<tr>
<td>850</td>
<td>80.0$^a$</td>
<td>90.0$^a$</td>
<td>95.0$^a$</td>
</tr>
<tr>
<td>Control</td>
<td>0.00$^d$</td>
<td>0.00$^d$</td>
<td>0.00$^d$</td>
</tr>
<tr>
<td>SE±</td>
<td>3.49</td>
<td>6.76</td>
<td>3.60</td>
</tr>
<tr>
<td>CV %</td>
<td>16.57</td>
<td>24.41</td>
<td>11.02</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same latter(s) are not significantly different according to Duncan Multiple Range Test (DMRT) at p ≤ 0.05.
Table (6c) Effect of different doses of Selecton on the mortality% of cotton mealybug on eggplant compared with LD$_{90}$

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Mortality %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hrs</td>
</tr>
<tr>
<td>1152</td>
<td>92.5 a</td>
</tr>
<tr>
<td>576</td>
<td>82.5 a</td>
</tr>
<tr>
<td>288</td>
<td>62.5 b</td>
</tr>
<tr>
<td>144</td>
<td>65.0 b</td>
</tr>
<tr>
<td>1000</td>
<td>80.0 a</td>
</tr>
<tr>
<td>Control</td>
<td>0.00 c</td>
</tr>
<tr>
<td>SE±</td>
<td>4.85</td>
</tr>
<tr>
<td>CV %</td>
<td>15.22</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same latter(s) are not significantly different according to Duncan Multiple Range Test (DMRT) at p ≤ 0.05.
CHAPTER FIVE
SUMMARY AND CONCLUSION

1. The (ANCMB) and (ILCMB) can reach the peak on tomato and eggplant during March, October and November where the temperature was high (30-40ºc) and the RH was low (20-30%) and low during January and August where the temperature was low (20-25ºc) and the RH was high (60-80%). Hence, the chemical control if needed should be carried in early January and early September to avoid CMB to reach the ETL.

2. The CMB developmental stages need more time on eggplant than on tomato.

3. Each female of CMB lays only one ovisack during its entire life span.

4. CMB has three nymphal instars, the total life on tomato and eggplant completed in 26.9±9.7 and 35.7±11.2, respectively.

5. Predators found were *Exochomus nigromuculatus*, *Scymnus sp.* (Coccinellidea).

6. The insecticides Diazinon, Sinomat and Selecton were effective to control CMB.
CHAPTER SIX
RECOMMENDATIONS

1. Tomato and eggplant should not be intercropped when the CMB was expected to occur during the season or even subsequent and/or overlapping each other in the cropping system.

2. Chemical control of CMB (if needed) should take place in February and September to avoid the high level of population density and infestation intensity in March and October.

3. Further work should be conducted on the ETL of CMB on vegetable crops and its natural enemies.

4. Diazinon, Sinomat and Selecton insecticides were primary as control measure CMB on tomato and eggplant after large scale experiment.
REFERENCES


## Appendices

### Appendix (1) Number of nymphs/female of CMB

<table>
<thead>
<tr>
<th>Number of ovisack</th>
<th>Number of nymph/ovisack</th>
<th>Total number of nymph</th>
</tr>
</thead>
<tbody>
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<td>0 - 100</td>
<td>48,75,52,42,47,69,65,66,46,75,78,94,79,94,59,30,91,97,97,63,74,83,89,77,85,100,35,76,38,49,78,53,73,55,52,70,75,58,86,93,90,99,83</td>
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<td>4658</td>
</tr>
<tr>
<td>301 - 400</td>
<td>373,362,302,303,357,309,366,334,385,</td>
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<tr>
<td>401 - 500</td>
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## Appendix (2) Period taken by first nymphal instar in days on tomato and eggplant

<table>
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<th>Tomato</th>
<th></th>
<th>Eggplant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of first instar nymphs</td>
<td>Period taken (days)</td>
<td></td>
<td>Number of first instar nymphs</td>
<td>Period taken (days)</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td></td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
<td></td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td></td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td></td>
<td>4</td>
<td>7</td>
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<tr>
<td>Total</td>
<td>38</td>
<td></td>
<td>Total</td>
<td>34</td>
</tr>
<tr>
<td>Range</td>
<td>3 _ 6</td>
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<td>4 _ 8</td>
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<tr>
<td>Mean ± SD</td>
<td>4.5 ± 1.29</td>
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<td>Mean ± SD</td>
<td>6 ± 1.58</td>
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Appendix (3) Period taken by second nymphal instar in days on tomato and eggplant

<table>
<thead>
<tr>
<th>Number of second instars nymph</th>
<th>Period taken by (days)</th>
<th>Number of second instars nymph</th>
<th>Period taken by (days)</th>
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<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>2</td>
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</tr>
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<td>7</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>6</td>
<td>8</td>
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<td>14</td>
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<td>9</td>
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<td></td>
<td>5</td>
<td>11</td>
</tr>
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<td></td>
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<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Total 38</td>
<td>33</td>
<td>Total 34</td>
<td>76</td>
</tr>
<tr>
<td>Range</td>
<td>4 – 9</td>
<td>Range</td>
<td>5 – 4</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>6.6 ± 2.07</td>
<td>Mean ± SD</td>
<td>9.5 ± 2.87</td>
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</table>
Appendix (4) Period taken by third nymphal instar in days on tomato and eggplant

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<th>Tomato</th>
<th>Eggplant</th>
</tr>
</thead>
<tbody>
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<td>Number of third instar nymphs</td>
<td>Number of third instar nymphs</td>
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<td>2</td>
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<td>9</td>
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<tr>
<td>8</td>
<td>2</td>
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<tr>
<td>10</td>
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<td>6</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total 38</td>
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<tr>
<td>Range</td>
<td>3 _ 9</td>
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<tr>
<td>Mean ± SD</td>
<td>6 ± 2.16</td>
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Appendix (5) Pre oviposition, oviposition and post oviposition period (days) of *P. solenopsis* on tomato

<table>
<thead>
<tr>
<th>Number of adult female studied</th>
<th>Pre oviposition period (days)</th>
<th>Oviposition period (days)</th>
<th>Post oviposition period (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
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<td>7</td>
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<td>5</td>
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<td>Range</td>
<td>1 - 5</td>
<td>1 - 7</td>
<td>2 – 7</td>
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<td>Mean±( SD)</td>
<td>3.2±1.31</td>
<td>3.7±1.77</td>
<td>2.9±1.12</td>
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</table>
Appendix(6) ) Pre oviposition, oviposition and post oviposition period (days) of *P. solenopsis* on eggplant

<table>
<thead>
<tr>
<th>Number of adult female studied</th>
<th>Pre oviposition period (days)</th>
<th>Oviposition period (days)</th>
<th>Post oviposition period (days)</th>
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<tbody>
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<td>1</td>
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<td>7</td>
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<td>3</td>
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</tr>
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</tr>
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</tr>
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<td>3</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>45</td>
<td>65</td>
</tr>
<tr>
<td>Range</td>
<td>2-4</td>
<td>2-8</td>
<td>2-5</td>
</tr>
<tr>
<td>Mean ±(SD)</td>
<td>3±0.90</td>
<td>4.33±1.72</td>
<td>2.66±0.85</td>
</tr>
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</table>
Appendix 7(a,b,c,d,e,f,g, h,I ) The relationship between temperature, mean number of CMB and infestation level of CMB on tomato, winter season 2016.

\[ y = 6.032x - 178.1 \]
\[ R^2 = 0.624 \]

\[ y = 4.911x - 43.87 \]
\[ R^2 = 0.443 \]

\[ y = 1.007x + 20.87 \]
\[ R^2 = 0.013 \]

\[ y = 6.760x - 1406 \]
\[ R^2 = 0.653 \]
$y = 0.021x + 82.87$

$R^2 = 0.004$
Appendix 8 (a,b,c,d,e,f,g,h,I) The relationship between temperature, mean number of CMB and infestation level of CMB on eggplant, winter season 2016.

(a) The relationship between maximum temperature and mean number of mealybug:

\[ y = 2.019x - 63.15 \]
\[ R^2 = 0.538 \]

(b) The relationship between minimum temperature and mean number of mealybug:

\[ y = 1.571x - 16.59 \]
\[ R^2 = 0.359 \]

(c) The relationship between range temperature and mean number of mealybug:

\[ y = 0.371x + 3.178 \]
\[ R^2 = 0.014 \]

(d) The relationship between average temperature and mean number of mealybug:

\[ y = 2.184x - 48.13 \]
\[ R^2 = 0.541 \]
**Graphs e, f, g, and h**

**Graph e**
- Maximum temperature
- Infestation % vs. Temperature
- Equation: $y = 5.284x - 126.6$
- $R^2 = 0.878$

**Graph f**
- Minimum temperature
- Infestation % vs. Temperature
- Equation: $y = 2.853x + 16.77$
- $R^2 = 0.282$

**Graph g**
- Range temperature
- Infestation % vs. Temperature
- Equation: $y = 2.772x + 12.27$
- $R^2 = 0.186$

**Graph h**
- Average temperature
- Infestation % vs. Temperature
- Equation: $y = 4.908x - 65.70$
- $R^2 = 0.650$
Appendix 9 (a,b,c,d,e,f,g,h,I ) The relationship between temperature, mean number of CMB and infestation level of CMB on tomato, rainy season 2016.

(a) $y = 7.1144x - 235.96$
$R^2 = 0.716$

(b) $y = -1.733x + 61.114$
$R^2 = 0.0403$

(c) $y = 3.9987x - 36.373$
$R^2 = 0.4954$

(d) $y = 6.415x - 162.02$
$R^2 = 0.2483$
The graph shows the relationship between infestation percentage and the mean number of mealybugs. The equation of the line is $y = 0.351x + 75.57$ with an $R^2 = 0.278$. The scatter plot indicates a positive correlation between the two variables.
Appendix 10 (a,b,c,d,e,f,g,h,I) The relationship between temperature, mean number of CMB and infestation level of CMB on eggplant, rainy season 2016.

\[ y = 3.039x - 102.2 \]
\[ R^2 = 0.461 \]

\[ y = -2.067x + 53.10 \]
\[ R^2 = 0.202 \]

\[ y = 2.283x - 25.68 \]
\[ R^2 = 0.569 \]

\[ y = 1.265x - 27.93 \]
\[ R^2 = 0.034 \]
e. Infestation % vs. Maximum temperature

\[ y = 9.147x - 284.4 \]
\[ R^2 = 0.444 \]

f. Infestation % vs. Minimum temperature

\[ y = -7.243x + 205.0 \]
\[ R^2 = 0.264 \]

g. Infestation % vs. Range temperature

\[ y = 7.312x - 60.61 \]
\[ R^2 = 0.622 \]

h. Infestation % vs. Average temperature

\[ y = 2.673x - 27.81 \]
\[ R^2 = 0.016 \]
$y = 2.282x + 29.69$

$R^2 = 0.555$
Appendix (11) The LD$_{90}$ of Diazinon on cotton mealybug

<table>
<thead>
<tr>
<th>Doses (ppm)</th>
<th>Tested 24</th>
<th>Corrected</th>
</tr>
</thead>
<tbody>
<tr>
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<td>89.7</td>
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<td>100</td>
<td>72.5</td>
<td>71.8</td>
</tr>
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<td>10</td>
<td>52.5</td>
<td>51.3</td>
</tr>
<tr>
<td>5</td>
<td>45</td>
<td>43.6</td>
</tr>
<tr>
<td>2.5</td>
<td>25</td>
<td>23.1</td>
</tr>
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<td>1.25</td>
<td>17.5</td>
<td>15.4</td>
</tr>
<tr>
<td>0.6</td>
<td>20</td>
<td>17.9</td>
</tr>
<tr>
<td>0.3</td>
<td>7.5</td>
<td>5.1</td>
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</tbody>
</table>

R- square 0.95  

a = 4.05  
b = 0.78  

SE-y = 0.094  
SE-x = 0.069  
LD$_{90}$ = 722.72  
LD$_{50}$ = 16.52  
LD$_{10}$ = 0.3775
Appendix (12) : The LD$_{90}$ of Sinomat on cotton mealybug

<table>
<thead>
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<th>Doses (ppm)</th>
<th>Tested 24</th>
<th>Corrected</th>
</tr>
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<tbody>
<tr>
<td>1000</td>
<td>92.5</td>
<td>92.5</td>
</tr>
<tr>
<td>100</td>
<td>57.5</td>
<td>57.5</td>
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<tr>
<td>10</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>2.5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1.25</td>
<td>7.5</td>
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<tr>
<td>0.6</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>0.3</td>
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<td>5</td>
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<tr>
<td>R-Square</td>
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<td></td>
</tr>
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<td>a = 3.67</td>
<td>b = 0.89</td>
<td></td>
</tr>
<tr>
<td>SE-y =</td>
<td>0.093</td>
<td></td>
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<tr>
<td>SE-x =</td>
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<td>LD$_{90}$</td>
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<td>LD$_{50}$</td>
<td>31.21</td>
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<td>LD$_{10}$</td>
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</table>
Appendix (13) : The LD<sub>90</sub> of Selecton on cotton mealybug

<table>
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<td>15.4</td>
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R-Square 0.925

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b = 0.8

SE-y 0.127

SE-x 0.093

LD<sub>90</sub> 1000

LD<sub>50</sub> 25.11

LD<sub>10</sub> 0.63
Appendix (14): Degree of temperature, winter, rainy season 2016

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Appendix(15a): Mean of Relative Humidity

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Appendix (16): Ovisack and eggs deposited by female of mealybug

Appendix (17): Adult female of mealybug
Appendix (18): Adult male of mealybug
Appendix (19) Tomato infested by CMB