بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of graduate Studies

Management, Biology and Ecology of the Fall Army Worm, *Spodoptera frugiperda* (J.E.Smith)

(Lepidoptera: Noctuidae) in Sudan

إدارة وبايولوجيا وبيئة دودة الحشد الخريفية فى السودان

A Thesis Submitted in Partial Fulfillment of the Requirements for the Ph.D. Degree in Plant Protection

By

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الآيه

بسم الله الرحمن الرحيم

قال تعالي: (يَا أَيُّهَا النَّاسُ ضُرِبَ مَثَلٌ فَاسْتَمِعُوا لَهُ ۚ إِنَّ الَّذِينَ تَدْعُونَ مِنْ دُونِ اللَّهِ لَنْ يَخْلُقُوا ذُبَابًا وَلَوِ اجْتَمَعُوا لَهُ ۖ وَإِنْ يَسْلُبْهُمُ الذُّبَابُ شَيْئًا لَا يَسْتَنْقِذُوهُ مِنْهُ ۚ ضَعُفَ الطَّالِبُ وَالْمَطْلُوبُ (٧٣)

Dedication

To my beloved mother

To the Soul of my Father

To my brothers and sisters

To my dear wife

To my children

NADA

Acknowledgments

In the beginning I render my acknowledgement to the Almighty Allah.

My sincere thanks and gratitude are due to my supervisor prof. Awad Khalafalla Taha Elhag For all helpful assistance, guidance, patience, continuous and un-limited support and keen supervision during this work.

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Abstract

A survey was conducted to determine the levels of infestation, distribution and main hosts of fall army worm in 2018, one year after it,s discovery in Sudan. The Survey included 15 sites in nine States (eg, Northern, Khartoum, Al Gazira, Sinnar, Gedaref, Kassala, Blue Nile, South Kordofan and West Darfur States,).

The final results of the survey showed that the affected area reached about 22.06% of the total area surveyed (more than 6ooo feddan). The main host plants found were Maize (*Zea mays)* Sorghum (*sorghum Bicolor)*, Sunflowres (*Helianthus giganteus*), Sesame (*sesamum indicum*), paenut (*Aarchis hypogaea*), Tomatoes (*Solanum lycopersicum*) and Millet (*pennisetum glaucum*) With special preference to maize.

In Khartoum State, the studies conducted showed that there was significant difference between Mean Percentage of damage of the FAW in five areas (Shambat, Alshehainab, Touti Alfaki-Hashim and Kafouri) during October, November and December (2018). Mean Percentage of damage of the FAW in November and December was significantly higher than October. Also, The Mean Percentage of damage of the FAW in Shambat and Alshehainab, Touti were significantly higher than Alfaki-Hashim and Kafouri.

Detailed laboratory experiments were carried out to study the life cycle and annual generations of the fall army worm. In this respect Randomized Complete Block Design (RCBD) were carried out during the period from September 2018 up to August 2019. The Fall armyworm (FAW) was reared in the laboratory and fed on a nutrient medium composed of corn leaves. The results displayed the range of eggs laid by a female was 890–1169 eggs. The egg incubation period ranged between 3-13 days. The larval duration ranged

between (13-50) days and the pupal duration was ranged between (7-20) days under a temperature of 21-30°c and a Relative Humidity (RH) of 65 ± 5%. The longevity of the adults was 1-20 days, and the range of the full lifecycle was (24-100) days. Six generations of FAW were obtained within one year. This study also showed that in Sudan FAW breeds continuously through out the year

The results of the collection and identification of natural enemies of fall army worm in Khartoum State showed that, there are more than 20 different species of natural enemies. The collection of predators included: 5 species from Coleoptera, two species from Hemiptera, two species from Dermaptera, 5 species from Hymenoptera,3 different species of flies from Dipter. In addition, a number of larvae were found infected by different species of micro-organisms.

With respect to biological control of this pest experiments with an extract of a solution of Pathogenic Micro-organisms was tried and the result showed a good efficacy against FAW larvae under field condition.

Furthermore and looking for efficient, less cost and environmentally friendly plant extract control methods for controlling fall armyworm worm in cereal crops. A Complete Randomized Block Design (CRBD) experiments with three replications were conducted in the laboratory to investigate the insecticidal effects of four plant extracts consisting of ethanolic extract of Neem (*Azadirachta indica)* seeds, Black pepper (*Piper nigrum*) seeds, Usher (*Calotropis procera*) leaves and water extracts of Argel (*Solenostemma argel)* leaves on larvae of the Fall armyworm (FAW) (*Spodoptera frugiperda).* Newly emerged larvae of FAW were treated topically by 4 concentrations (10, 25, 50 and 75%) of each extract, and then the larval mortalities were calculated after 24, 48 and72 hrs. The results showed that, the highest concentrations (75%) of the three ethanolic extracts gave higher mortality percentages (100%) after 72 hrs of exposure, compared with other concentrations. Also, these were not significantly different from the recommended dose of the standard pesticide “Spinosad”. On the other hand, Argel water extract showed no effect on the (FAW) larvae.

الملخص العربي

تم اجراء المسح لتحديد مستويات الاصابه والتوزيع والعوائل الاساسيه لدودة الحشد الخريفيه في العام 2018 بعد عام واحد من اكتشافها في السودان. شمل المسح خمسة عشر موقع فى تسع ولايات (الولايه الشماليه. ، الخرطوم ، الجزيره، سنار، القضارف، كسلا ،النيل الازرق ،جنوب كردفان و شرق دارفور).

اظهرت النتائج النهائيه للمسح ان المنطقه المصابه بلغت حوالى 22.06% من اجمالى المساحة التى تم مسحها (اكثر من 6000 فدان). العوائل الاساسيه لدودة الحشد الخريفية التى وجدت هى الذرة الشاميه، و الذرة الرفيعة وزهرة الشمس والسمسم والفول السودانى ، و الطماطم ،والدخن، وافضلها الذرة الشاميه .

. فى ولاية الخرطوم ، اوضحت الدراسه ان هناك فروقا معنويه فى متوسط نسبة الضرر للحشره فى خمس مناطق زراعية شمبات والشهيناب وتوتى والفكي هاشم وكافوري خلال اكتوبر ،نوفمبر وديسمبر فى العام 2018م ايضا، اظهرت النتائج ان نسبه الضرر الطبيعى فى ديسمبر ونوفمبر اكثر من اكتوبر . كما اوضحت الدراسه ان متوسط نسبه الضرر الطبيعى فى مناطق شمبات وتوتى والشهيناب اعلى معنويا من كافورى والفكى هاشم .

اجريت التجارب المعمليه التفصليه لدراسة دورة الحياة والاجيال السنويه لدودة الحشد الخريفيه، واجريت التجارب باتباع التصميم العشوائ الكامل (RCBD) خلال الفترة من سبتمبر 2018 حتى نهايه اغسطس 2019 تم تربيه الحشرة فى المعمل وغذيت على مادة مغذيه تتكون من اوراق الذرة . أظهرت النتائج ان كتل البيض التى وضعها الانثي تراوحت بين 1169-890 بيضه ، فترة حضانه البيض تراوحت بين 3-13 يوم وتراوحت فترة اليرقه مابين 13-50 يوم وفترة العذراء تراوحت مابين 7-20 يوم تحت درجه حرارة 21-30 درجه مؤيه ورطوبه نسبيه 65+5%. كان مدى عمر البالغين 1-20 يوم ومدي دورة الحياة الكامله 24-100 يوم ، وتم الحصول سته اجيال من دودة الحشد الخريفية فى غضون عام واحد . ايضا اوضحت هذه الدراسة الى ان دودة الحشد الخريفية فى السودان تتكاثر باستمرار .

اظهرت نتائج جمع الاعداء الطبيعيه والتعرف عليها فى ولايه الخرطوم ان الاعداء الطبيعيه لدودة الحشد الخريفيه هي اكثر من 20 نوعا ضمت المفترسات :خمسه انواع من حشرات غمديه الاجنحة

ونوعان من جشرات جلدية الاجنحة وخمسه انواع من حشرات غشائية الاجنحة ونوعان من حشرات نصفية الاجنحه وثلاثه انواع من ذات الجناجين بالاضافه الى ذلك تم العثور عدد من اليرقات مصابه بانواع مخلتفه من الكائنات الحيه الدقيقه .

ايضا اظهرت نتائج المكافحة البايولوجيه بمستخلص محلول اليرقات الميته (الفيروسات والبكتريا والفطريات) فى منطقة الشهيناب في ولايه الخرطوم فعاليه عاليه ضد يرقات دودة الحشد الخريفيه.

كان من أهداف هذه الدراسة ايضا البحث عن مستخلص نباتى فعال واقل تكلفة وصديق للبيئة لمكافحة دودة الحشد الحريفية. تم اجراء التجارب بالتصميم العشوائ الكامل بثلاث مكررات فى المختبر للتحقق من تاثير المستخلصات الاربعة لكل من بذور النيم ،وثمار الفلفل،واوراق العشر، واوراق الحرجل على يرقات دودة الحشد الخريفية . عولجت يرقات دودة الحشد الخريفية التى ظهرت حديثا موضعيا باربعة تراكيز(10%، 25% ، 50%، و75%) من كل مستخلص ، ثم تم حساب نفوق اليرقات بعد 24و48و72 ساعة اظهرت النتائج ان اعلى تركيز (75 %) من المستخلصات الايثانولية الثلاثه اعطت اعلي نسبة موت (100%) بعد 72 ساعة من التعرض ، مقارنة بالتركيزات الاخرى ، أ يضا لم تكن هذه النسبة تختلف بشكل كبير عن تاثير الجرعة الموصى بها من المبيد القياسى سبينوساد ، من ناحية اخرى اوضحت النتائج ان المستخلص المائ لاوراق الحرجل ليس له تاثير على اليرقات .

CHAPTER ONE

1. INTRODUCTION

The Fall army worm (*Spodoptera frugiperda*, (J.E.Smith) (FAW), is an insect native to tropical and subtropical regions of America. (Ashley, 1979, Spark, 1986). FAW larvae can feed on more than 80 plant species, including maize, rice, sorghum, millet, sugarcane, vegetable crops and cotton (Blanco *et al.*, 2016). FAW can cause significant yield losses if not well managed. It can have several generations per year and the moth can fly up to 100 km per night. In the African Contenent, FAW was first detected in Central and Western Africa in early 2016 in Benin, Nigeria, Sao Tome and Principe, and Togo and further reported and confirmed in the whole mainland of Southern Africa, and in Madagascar, and Seychelles (Island State) (Goergen *et al.*, 2016). In January 2018, FAW had been detected and reported in almost all Sub Saharan African countries, except Djibouti, Eritrea, and Lesotho (FAO, 2018).

In Sudan, the fall armyworm (FAW), *Spodoptera frugiperda,* was recorded for the first time in the experimental farm of Damazin Research Station, Blue Nile State, on Maize Hybrids in 17 July 2017 (El Nour *et al*, 2017; Abrahams *et al.*, 2017). In Gedaref State, F A W was recorded on Maize (variety Hudiba 93 and a Turkish Hybrid) in the experimental farm of the Research Station in August 2017 (Gadaref Research Station, 2017). A general survey was carried out in Blue Nile State showed that, the FAW affected more than 15,000 Feddan of Maize and Sorghum in Rusaris, Gesan, and Wad Almahi localities. In Gedaref, the FAW was recorded in different areas (eg.Samsam, Fashaga, Doka and 3 other areas) on sorghum. Also, distribution of this pest extended to Sinnar State (on sorghum and maize), Gazira State (on maize) and Khartoum State (on maize and Abu Sabeen).

The FAW was also recorded later in River Nile and Northern States (Jubara, 2018). The Survey carried out in different areas also confirmed the presence and spread of *S. frugipera*. Specimens of adult stage were collected from Gadaref, Dmazin and Gezira after being reared in the laboratory. The specimans and Photos of adult males and females collected from different areas (eg., Gedarif, Damazin and Gazeira) were sent to Dr. Bayeh Mulatu, IPM (FAO, Ethiopia) and he confirmed that it is *S.Frugiperda.* Fall armyworm attack all stages of the plant from seedling and tasseling causing defoliation, killing of young plants, tunnel into the stem and attack ears resulting in grain damage and subsequently reduce quantity and quality of the yield (Peairs and Sanders, 1979). Recent studies conducted by Center for Agriculture and Bioscience International (CABI) in 12 maize-producing African countries showed that, without proper management, FAW can cause annual maize yield losses between 8 – 21 million tones, leading to monetary losses of up to US$ 6.1 billion, while affecting over 300 million people in Africa, who, directly or indirectly, depend on the crop for food and well-being (Abrahams *et al.,* 2017; Midega *et al.,* 2018). Larvae of FAW cause damage to the plant by consuming the foliage. Neonate larvae mainly feed on leaf tissue whereas the second and third instars feed on the leaves making holes in them, typical damage symptoms of FAW (Belay *et al*., 2012).

Since the occurrence of FAW in African countries, insecticides have been widely used as emergency response to halt distribution of the pest and minimize damage in maize fields. Although insecticides play important role in FAW management, confirmed reports of insecticide resistance development in FAW population (Yu, 1991) showed that, in addition to other adverse effects, sole dependence on insecticides is not feasible. It is imperative to use integrated pest management strategy for FAW. There are no registered insecticides for FAW control in African countries, suggesting urgent need for insecticide screening. Farmers complained that the currently used insecticides are not effective against the FAW; hence, they were forced to use high dose and with high frequency of applications.

Botanical insecticides have long been considered as attractive alternatives to synthetic chemical insecticides for pest management. Botanical insecticides are eco-friendly, economic, target specific and biodegradable. Several plant extracts have been reported to have insecticidal properties against stemborers in cereals.These include Neem (*Azadirachta indica)*; Chinaberry tree (*Persian Lilac)*, (*Melia azadirach)*; Acacia (*Acacia sp)*; Bean (*Tephrosia vogelii)* ; Wild marigold (*Tagetes minuta)*; wild sage (*Lantana camara)*; West African pepper (*Piper nigrum)*; Jatroph (*Jatropha curcas)*; Chillies (*Capsicum spp*); onion (*Allium sativum)*, (*Allium cepa)*; Lemon grass (*Cymbopogon citrates);* Tobacco (*Nicotina spp)*; Wild Sunflower (*Tithoni diversifolia)*. etc. (Ogendo *et al.*, 2013; Mugisha-Kamatenesi *et al*., 2018; Stevenson *et al*., 2017). Preliminary evidence indicates that seeds or leaves of plants of the Meliaceae family (*Azadirachta indica*, i.e. neem and Melia) and Asteraceae family (Pyrethrum) and other plants such as *Tephrosia vogelii* or The *vetia neriifolia* are showing efficacy in the management of army worms(Al-Jboory, 2017).

Several predators were recorded prying on *S. frugiperda* in the field. The most common predators were the true bugs, *Castolus sp*., *Podisus sagittal* and *Zelus longipes* which attack larger *Spodoptera frugiperda* larvae; the Coccinellidae *coleomegilla sp*., Chrysopidae, *Doru spp* (Dermaptera) and the bug *Orius sp.* that attack newly emerged larvae (Fritzsche Hoballah, 2001). FAW is also attacked by a number of entomopathogens including viruses, fungi, protozoa, nematodes, and bacteria. These cause significant level of mortality in FAW population and help to reduce leaf defoliation in maize (Ali *et al*., 1996). However, empirical information on this approach is still scanty in Africa. Lepidoptera pheromones have been successfully used for insect monitoring, mass trapping, and mating disruption for a diverse of insect pests including the FAW (Wyatt, 1998).

Studies on FAW:

As indicated in the literature, FAW has been a major pest on different crops in Tropical Americas. Many studies were carried out on the different aspects of the FAW, biology, ecology and control in those countries (Sparks. 1979). Recently, the FAW also became a major threat to agricultural crops in many African countries since its discovery in the Continent in 2016 (IAPPS, 2016). By the beginning of 2018, the distribution of the pest has extended to more than 60 African countries (FAO, 2018). During the years (2016 & 2017), also many reports were published on the biology and ecology of the FAW, and about the measures that should be applied for its control and management (FAO, 2018).

In Sudan, FAW was recorded for the first time in Blue Nile State (Damazin). By the end of the year 2017, and up to March 2018, FAW distribution was recorded in 6 other States in the country (Gedarif, Gazira, Sinnar, Khartoum, River Nile and Northern State). Since the discovery of this major pest in Sudan during the last few years, no study has been carried out on its detailed biology, ecology under Sudan conditions. Also, so far, no studies were made on its control and management.

Accordingly, this study was initiated to evaluate the threat of the FAW to different crops in Khartoum State, and how to apply a pest management programme against this pest.

<u>The Objectives of this study</u> :

1- To studies about general Survey on the distribution, host range and assessment of damage of the Fall Armyworm (FAW) in selected sites in a number of States, in the country.

2- To studies on the Biology, Ecology and population dynamics of (FAW) in Khartoum State.

3- To studies collection, Identification, and studies on the naturally occurring biological control agents on the different stages of the (FAW) in Khartoum State,

4-To studies microbial control Trials through Application of an extract of a mixture of Pathogenic micro-organisms.

5- To application of laboratory, semi-field and field control trials of the Fall Armyworm using plant extracts.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Taxonomy of Fall Armyworm, *Spodoptera frugipera*

(Lepidoptera: Noctuidae)

Scientific name *Spodoptera frugiperda* J.E. Smith

Taxonomic position

Phylum: Arthropoda

Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Common name: fall army worm (FAW)

Order Lepidoptera is one of the largest insect orders in class: Insecta and contains butterflies and moths. Butterflies and moths are characterized by scales on their wings that come off when they are handled. Many species in the order Lepidoptera are economically important pests feeding on plants, stored grains or fabrics. Insects that belong to the order Lepidoptera undergo complete metamorphosis. The genus *Spodoptera* belongs to the family Noctuidae where the moths are nocturnal. Noctuidae larvae are smooth and dull colored most of them feed on foliage of plants and few on fruits (Borror *et al*., 1989). The genus *Spodoptera* consists of a number of species that are important crop pests including *S. littoralis* (Boisduval) (the Egyptian cotton leaf worm), *S. exempta* (Walker) (the African armyworm), *S. litura* (Fabricius) (the tobacco caterpillar), *S. exigua*

(Hubner) (the beet army worm), *S. ornithogalli* (Guenée) (Yellow striped army worm), and *S. frugiperda* (J.E. Smith) (the fall army worm). The larvae of the African armyworm are major pests of cereals and rangeland in many sub- Saharan African countries; during outbreaks, the species population size and invasion areas can be vast (CABI, 2017; Erik, 2017)

2.2 Origin and Distribution of Fall Armyworm:

The fall armyworm (FAW), *S. frugiperda*, is native to the tropical regions of the western hemisphere from the United States to Argentina. *S. frugiperda* is an important pest of maize and many other crops throughout the Americas, remaining one of the most common Lepidoptera pests in the United States (Ferreira, 2015). causes significant damages to the cultivated crops of economic importance such as maize, sorghum, sugarcane but also other legumes and cotton. It is a quarantine pest with a large dispersal potential which has been intercepted several times in Europe (Erik, 2017). *Spodoptera frugiperda* has been reported for the first time in 2016 in Africa, in Nigeria, Sao Tomé, Benin and Togo (Erik, 2017) causing significant damages to maize. It has been confirmed in Ghana (CABI, 2017; Erik, 2017) and Zimbabwe (Erik, 2017; FAO, 2018) and some cases have been recorded in Malawi, Mozambique, Namibia, South Africa and in Zambia (Erik, 2017). In Ethiopia FAW was reported for the first time in Bench Maji zones of Southern Nations, Nationalities and Peoples State in January 2017 (Teshome *et al*., 2018). In Sudan, FAW was recorded for the first time 2016 in Blue Nile State (Damazin) (Gedaref Research Station 2017). By the end of the year 2017, and up to March 2018, FAW distribution was recorded in 6 other States in the country (Gedaref, Gazira, Sennar, Khartoum, River Nile and Northern State (Jubara, 2018)

2.3 Biology of Fall Armyworm:

The life cycle of the (FAW) is completed in about 30 days during the summer, but 60 days in the spring and autumn, and 80 to 90 days during the winter (Capinera, 2014). Like all insects, fall armyworm development rate is greatly affected by temperature. In a laboratory study, conducted with caterpillars feeding on maize leaves at constant temperatures, the larval stage lasted about 22 days at 70 °F, 14 days at 80 °F, and 10 days at 90 °F. Development rate is faster at higher temperatures, although it does begin to decline at temperatures above 93 °F. Fall armyworms cannot survive freezing temperatures. Populations usually begin to decline a little before first frost because fall armyworms cannot develop at temperatures below about 50 °F (Silva *et al*., 2015). The number of generations occurring in an area varies with the appearance of the dispersing adults. The ability to diapause is not present in this species. In Minnesota and New York, where fall armyworm moths do not appear until August, there may be but a single generation. The number of generations is reported to be one to two in Kansas, three in South Carolina, and four in Louisiana. In coastal areas of north Florida, moths are abundant from April to December, but some are found even during the winter months (Capinera, 2014). Eggs are usually laid on the upper surface of the leaves but occasionally they may be laid on other parts of the host plants. The egg of FAW is dome shaped with flattened base that measures about 0.4 mm in diameter and 0.3 mm in height. Eggs are laid in mass and number of eggs per mass can vary from 100 to 200. A single adult female can lay on average 1500 to 2000eggs during its life time (CABI, 2017). The first two larval instars feed gregariously on the underside of the young leaves, causing a characteristic skeleton or fenestration effect, and the plant's growth point can be destroyed. Larvae of larger size become cannibalistic and therefore one larva per spiral (cornea) is usual. The rate of larval development across the six stages is controlled by a combination of diet and temperature conditions, The larval period of about 14 – 30 days has been reported (Pitre and Hogg, 1983). Pupation takes place inside a soft cocoon in a soil cell, or rarely between the leaves on the host plant, and 9 to 13 days are required for development. Adults emerge at night and usually use their natural pre-oviposition period to fly several kilometers before settling for egg-laying, sometimes migrating over long distances. On average, adults live 12 to 14 days.

2.4 Nature of Damage:

The FAW is a polyphagous pest that attacks over 80 plant species (Capinera, 2005). It commonly feeds on field corn, sweet corn, sorghum, Bermuda grass, rice and grass weeds such as crabgrass and finger-grass. Other field crops that are frequently injured by FAW include alfalfa, barley, cotton, clover, oat, millet, peanut, ryegrass, sugar beet, Sudan grass, soybean, sugarcane, tobacco, and wheat (CABI, 2017). Young larvae initially consume leaf tissue from one side, leaving the opposite epidermal layer intact. By the second or third instar, larvae begin to make holes in leaves, and eat from the edge of the leaves inward. Feeding in the whorl of corn often produces a characteristic row of perforations in the leaves. Older larvae cause extensive defoliation, often leaving only the ribs and stalks of maize plants, or a ragged, torn appearance (Marenco *et al*, 1992) indicated that infestation by FAW on sweet corn causes more injury at late whorl stage compared to early and mid-whorl stages. Larvae of FAW burrow into the growing point of plants (buds, whorls, etc.) and destroy the growth potential of plants, or clip the leaves. In corn, they also burrow into the ear and feed on kernels like that of corn earworm, *Helicoverpa zea* (Boddie). But, unlike corn earworm, fall army worm will feed by burrowing through the husk on the side of the ear. Leaf damage by FAW and stem borer is also confusing. However, it is possible to determine which species is responsible for the damage through close examination, as the holes formed by FAW have smooth edges whereas holes cut by maize stem borer larvae have raged edges (Goergen *et al.*, 2016).

2.5 Management Methods of Fall Armyworm:

Detecting fall armyworm infestations before they cause economic damage is the key to their management (Ferreira, 2015). FAW monitoring can be done by capturing the flying moths with black light and pheromone traps. Pheromone traps are more efficient compared to backlight traps; they should be suspended at canopy height at the whorl stage in crops like corn. Trap catches can determine the presence or absence of the pest; however they are not necessarily good indicators of density. Other strategies have been used to manage fall armyworm including cultural practices, Biological (Parasitoids, Predators and Pathogens), botanicals and synthetic insecticides (Viegas Junior, 2003).

2.5.1 Cultural Methods:

Cultural control is an important component of pest management strategies including FAW. Sole maize cropping systems offer favorable environment to FAW to spread fast. FAW adult female moths find the preferred conditions to lay egg masses and increase the number of generations within a season, favoring increased levels of infestation. Plant diversity, including intercropping systems and the use of multiple varieties, can reduce the rate of ovipositon by confusing the FAW female moth, therefore helping reduce the level of infestation (FAO, 2018). A recent study has established that ,a climate-adapted version of Push-Pull, an already widely used technology developed by icipe and partners is effective in controlling the fall armyworm, providing a suitable, accessible, environmentally friendly and cost-effective strategy for management of the pest. These findings represent the first documented report of a readily available technology that can be immediately deployed in different parts of Africa to efficiently manage the fall armyworm. The study revealed fall armyworm infestation to be more than 80% lower in plots where the climate-adapted Push Pull is being used, with associated increases in grain yields, in comparison to monocrop plots. The findings were supported by farmers' perceptions through their own observations regarding significantly reduced presence of fall armyworm in Push-Pull plots (Midega *et al*., 2018). Similarly, most of subsistence farmers in Africa do not apply pesticides to maize to control pests; nevertheless, they do practice cultural control methods which deter or kill pests, such as maize intercropping, handpicking and killing of caterpillars, application of wood ashes and soils to leaf whorls (Fritzsche *et al.*, 2001). Survey conducted in Ethiopia and Kenya showed that, 14% and 39% of the farmers practiced cultural methods (such as handpicking) for FAW managements (Teshome *et al*., 2018).

2.5.2 Biological Methods:

Biological control can be considered as a powerful tool and one of the most important alternative control measures providing environmentally safe and sustainable plant protection. The success of biological control will depend on understanding the adaptation and establishment of applied biological control agents in agricultural ecosystems. Microbial pathogens and arthropod biocontrol agents have been successfully used in agricultural systems. They are safe for non-target vertebrates and for the environment, and production costs have been significantly reduced in recent times as they are mass produced in liquid media (Mahmoud, 2017). Even though biological control may not replace conventional insecticides, a number of parasitoids, predators and pathogens readily attack larval and adult stages of FAW.

2.5.2.1 Parasitoids and Predators:

The migratory behaviour of the FAW away from over-seasoning and reproduction sites makes the natural enemies less efficient. Various insects have been reported parasitizing *S. frugiperda* larvae and eggs. Ashley (1979) listed 53 species of parasitoids reared from *S. frugiperda* eggs and larvae. Only 18 of these are common to the continental United States, while 21 are present in South America and Central America, including Mexico. Ashley (1986) studied the impact on *S. frugiperda* population of eight native and one imported parasite in south Florida. These included: *Apanteles marginiventris, Campoletis grioti, Chelonus insularis, Meteorus autographae, Ophion spp., Rogus laphygmae, Ternelucha spp.* and *Eiphosoma vitticole* (imported). Although 63% of the first four larval instars were destroyed by parasitoids, he concluded that *S. frugiperda* has the reproductive potential to increase its population beyond regulation by native parasites. In Mexico, nine species of hymnopteran parasitoids and five species of dipteran parasitoids were recovered from FAW larvae Molina-Ochoa *et al*.,(2003) In hymnopteran parasitoids, five species belonged to the family Braconidae, three species belonged to the family Ichneumonidae, and only one species belonged to the family Eulophidae were recovered. In dipteran parasitoids four species belonged to the families Tachinidae and one species belong to Phoridae were recovered. Molina-Ochoa *et al*., (2004) recorded eleven species from three families of Hymenoptera: seven Braconidae, three Ichneumonidae and one Eulophidae from FAW larvae. According to Capinera (2005), *Cotesia marginiventris* and *Chelonus texanus* (both Hymenoptera: Braconidae), are the most commonly reared wasp parasitoids from larvae of FAW in the United States. Among fly parasitoids, *Archytas marmoratus* (Diptera: Tachinidae) is the most abundant larval parasitoids in the United States. In Kenya, Tachinid fly, *Archytas* *marmoratus* was also the main parasitoid with 12.5% parasitism. *Charops ater* and *Coccygidium luteum* were the commonly occurred parasitoids in Kenya; Tanzania with parasitism ranged from 6 – 12% and 4 – 8.3%, respectively Sisay *et al*., 2018). The predators of FAW are general predators that attack larvae of other lepidopterans. The most important predators of FAW include various ground beetles (Coleoptera: Carabidae); the striped earwig, *Labidura riparia* (Pallas) (Dermaptera: Labiduridae); the spined soldier bug, *Podisus maculiventris* (Hemiptera: Pentatomidae); and the insidious flower bug, *Orius insidiosus* (Hemiptera: Anthocoridae) (Capinera, 2001). Among the vertebrate predators, birds, skunks, and rodents are important ones that feed on larvae and pupae of FAW (Capinera, 2005).

2.5.2.2 Entomopathogens:

The development of resistance to synthetic insecticides is one of the driving forces for changes in insect pest management (Mahmoud, 2017). The use of microbial control is a potentially valuable alternative to chemical pesticides with their high cost, possible pest resurgence, development of resistance, and environmental contamination (Lezama Gutiérrez *et al*., 2001).

Entomopathogens may be used to supress insect population in at least three ways: (1) optimization of naturally occurring diseases, (2) introduction and colonization of pathogens into insect population as natural regulatory and (3) repeated application of pathogens as microbial insecticides (Wayne *et al*., 1980). Fall army worm is susceptible to at least 16 species of entomopathogens including viruses, fungi, protozoa, nematodes and bacteria (All *et al*., 1996; Wayne *et al.,* 1980). Among the pathogens, *Bacillus thuringiensis, Metarhizium anisopliae and Beauveria bassiana* are know to cause significant level of mortality in FAW population and help to reduce leaf defoliation in crops (Molina-Ochoa *et al*., 2003). Fungal pathogens such as, *M. anisopliae and B. bassiana* can cause a common disease in FAW larvae (Molina-Ochoa *et al*., 2003). Many of them occur naturally in fall armyworm population. Some cause natural epizootics (Wayne *et al*., 1980). Molina-Ochoa *et al*., (2003) recorded 3.5 % FAW larval mortality in Mexico due to naturally occurring entomopathogens and parasitic nematodes. The authors recovered three species of entomopathogenic fungi representing two different classes, Hyphomycetes (*Nomuraea rileyi,* and *Hirsutella sp.)* and Zygomycetes (*Entomophthora sp*.) from FAW larvae, and two additional species of Hyphomycetes (*Metarhizium anisopliae* and *Beauveria bassiana*) from soil samples.

2.6 Pheromone Lure:

Insect traps are important tools for monitoring pest populations in surveys and integrated pest management (IPM) programs. Traps can help detect invasions by new pest species, the onset of seasonal pest activity, determine the range and intensity of pest infestations, and track changes in pest populations, all of which help informed decision making for pest management (Wyatt, 1998). Traps typically use olfactory (chemical) and or visual cues or stimuli to attract pest insects. Phermone lures are a critical tool for detecting and managing insect pest populations (Spears, *et al*., 2016). Lepidopteran pheromones have been successfully used for insect monitoring, mass trapping, and mating disruption for diverse of insect pests (Wyatt, 1998).

Commercially available FAW sex pheromones have been used in the USA, and have been shown to be a useful tool for monitoring FAW males (Adams *et al*., 1989). Populations of adult male FAW are monitored in agricultural systems with a multi component sex pheromone as a lure in traps (Mitchell *et al*., 1989).

2.7 Synthetic Insecticides:

As it is true in many other insect pest species, insecticides are important management options in FAW control (Capinera, 2001). In Florida, fall armyworm is the most important pest of corn and insecticides are applied against FAW to protect both the early vegetative stages and reproductive stage of corn (Capinera, 2001). High volume of liquid insecticide is required to obtain adequate penetration and kill larvae feeding deep in the whorl of the plants. In situations where overhead sprinklers are used for irrigation, insecticides can also be applied in the irrigation water. Keeping plants free of larvae during the vegetative period can help to reduce the number of sprays needed at the silking stage (Foster, 1989). Hence, sprays should be spaced evenly during the growing period instead of concentrating at silking period.Yu (1991) reported that, a strain of the fall armyworm collected from corn in North Florida showed resistance to commonly used insecticides. Resistance to pyrethroids ranged from 2- to 216-fold; the highest resistance level observed was to fluvalinate. Resistance to organo phosphorus insecticides ranged from 12- to 271-fold; the highest resistance level observed was to methyl parathion. Resistance to carbamates ranged from 14- to 192-fold, with the highest resistance level being observed with carbaryl. Yu (1991) further indicated that the broad spectrum of insecticide resistance observed in the field strain was due to multiple resistance mechanisms, including increased detoxication of these insecticides by microsomal oxidases and target site insensitivity such as insensitive acetyl cholinesterase. Resistance management is a vital component of IPM. Pesticide resistance management will extend the useful life of valuable IPM-compatible pesticides. It is likely to be successful when combined with routine monitoring of pests, use of reasonable treatment thresholds, and make full use of non-pesticide methods, such as biological and cultural management, field sanitation and host plant resistance. Judicial and appropriate use of insecticides is essential for the successful management of FAW and to sustain increased productivity of maize in Africa. The recent invasion of FAW alarmed governments of different African countries to deploy a massive pesticide spray program as an emergency response in FAW affected areas, mainly in maize fields to protect crop damage and prevent further expansion of the pest. In recent surveys conducted in Ethiopia and Kenya it was noted that, farmers were applying different types of un-registered insecticides. That might be due to the invasive nature of the pest that, need rapid response and lengthy pesticide registration process (Teshome *et al.*, 2018). In Mexico, chemical control of *S. frugiperda* in maize is achieved by application of methyl parathion, chlorpyrifos, methamidophos, and phoxim, among other insecticides (Malo *et al*., 2001). Chlorantraniprole (Coragen), Flubendiamide (Belt SC 480), Spinetoram (Radiant) and Spinosad (Tracer) were effective in the control of *Tuta absoluta* on tomato (Hamdy *et al.*, 2013; MoA, 2017). Similarly, high mortality of fall armyworm was recorded with sprayed with this insecticide as compared to non-sprayed (Cruz *et al*., 2010; Hardke *et al*., 2011). Fall armyworm mortality on treated diets with Chlorantraniprole, lambda-cyhalothrin, spinetoram and flubendiamide were significantly higher (90.6 to 100%) than non-treated control, three days after treatment application (Hardke *et al*., 2011). According to Belay *et al*. (2012) Spinetoram, acephate, and thiodicarb caused significantly higher (60%) FAW mortality at 16 h after application, and the effects of spinosad, chlorantraniprole and cyhalothrin were intermediate under laboratory condition.

Dursban 48% EC *(chlorpyrifos-ethyl*) and Malathion 50% EC are registered for the control of armyworm, locusts and grasshoppers on cereals and pastures (MoA, 2017). Agro-Thoate 40% EC (Dimethoate 40%) also registered for the control of beanfly (*Ophiomiya phaseoli*), bean aphid (*Aphis fabae*); thrips (*Taenothrips spp*.) ABW (*Helicoverpa armigera*) on french beans, aphids (*Myzus persicae*) and ABW (*H. armigera*) on tomato, cabbage aphid and various aphids on cabbage and potato, respectively (MoA, 2017). Similarly, these synthetic insecticides have been registered for the control of FAW in the native region of the pest (Cruz *et al*, 2010)

2.8 Botanicals:

The use of botanical pesticides is considered as a substitute to hazardous synthetic pesticides such as pyrethroids and organophosphorus pesticides due to the disturbance in the environment, increasing user cost, pest resurgence and pest resistance to pesticides (Arya and Tiwari, 2013). As a result of serious impacts of the use of persistent and deleterious insecticides, research on the identification of eco-friendly and locally available alternative tools for pest control has been agenda of entomologist. Because of affordability and availabilities, farmers of developing countries used botanical insecticides for centuries to control insect pests of both field crops and stored produce (Schmutterer, 2009). Botanical insecticides are not only effective against crop pests but remain safer to natural enemies. Among many botanicals, plants such as *Azadirachta indica*, *Milletia ferruginea*,*Croton macrostachyus*, *Phytolacea docendra*, *Jatropha curcas*, *Nicotina tabacum* and *Chrysanthemum cinerariifollium* were successfully used to control insect pests (Schmutterer, 2009; Addisu *et al*., 2014). Some of these plant species possess one or more useful properties such as repellency, anti-feeding, antijuvenile hormone activity, oviposition/ hatching deterrence, antifertility or growth disrupters, biodegradability and ability to reduce insect resistance (Mochiah *et al*., 2011). *Melia azadirachata* belongs to the family Meliaceae is one of the potential bioactive plants extensively studied in laboratory and also in the field against several insect pests and vectors (Charleston, 2004). The compound cisdehydrocrotonin isolated from *Croton macrostachyus* bark inhibits the growth of lepidopteran pests (Viegas-Junior 2003). In rural areas of Ethiopia, *Schinus molle* is commonly used to drape branches over their head believing to repel housefly, *Musca domestica*. The traditional belief on repellent activities and also feeding deterrent was confirmed by two choice laboratory bioassay methods against houseflies (Wimalaratne *et al*., 1996). Hellpap (1995) tested three synthetic insecticides, and insecticidal plants (extracts of *J. curcas* and *A. indica*) against stem borer. Neem products were effective for control of stem borers, including the spotted stalk borer. A Preliminary field studies also showed that, application of extracts of chinaberry (*M. azedarach*), endod (*P. dodecandra*) and pepper tree (*S. molle*) significantly reduced the levels of leaf infestation and dead heart injury due to larvae of maize stalk borer, *Busseola fusca* (Asefa and Firdu, 1999). According to Asmare *et al*. (2006). The development of new insecticides from plant extracts sources can be an alternative for the control of *Spodoptera* spp. Species of different plant families and their derived products have received increased attention from scientists and more than 2000 plant species are already known to have insecticidal properties (Sukamar *et al*., 1991) Sudan with its variables geographical regions is rich in endogenous or an exotic plants which may represent a promising reservoir of naturally occurring toxicants that can be used as an effective components of integrated pest management (IPM) programmes. In the Sudan examples of the promising chemical source plants includes, neem tree, *Azadirachta indica* (A. Juss), sadom apple (Usher) *Calotropis procera* (J), fenugreek (Hilba) *Trigonella foenum* (G), (garlic) *Allium sativum* (L),(sesame) *Sesamum indicum* (L) and sweet basil (Rehan) *Ocimum basilicum* (L)(Fager, 1999).

Concerning problems and hazards of insecticide applications, many studies to control FAW were carried out using plant extracts (Silva *et al.*, 2015; Sisay *et al.*, 2019).

2.8.1 Neem:

2.8.1.1 Taxonomy

Kingdom: Plantae

Division Magnoliopsida

Order: Sapindales

Suborder: Rutinease

Family: Meliaceae

Genus: Azadirachta

Species: Indica

S.N : *Azadirachta Indica.A.juss*

E.N: Neem

(Vietmeyer, 1992, and Schmutterer, 2002)

2.8.1.2 Origin:

The Neem is versatile tree of Indian and Burma origin where the ancient healers of that region knew it very well in health (ICIPE, 2002).

2.8.1.3 Morphology:

Neem is a fast growing tree that can reach a height of 15-20m, rarely to 35 -40 m. Itis ever green, but under severe drought it shed mostly or nearly all of it leaves. The branches are wide spread, the fairly dense crown is roundish or oval, may reach a diameter of 15-20m. In old tree standing specimen the trunk is relatively short, straight and many reach a diameter of 1.2m. The bark is hard fissured or reddish-brown. The sap wood is grayish white and heart wood reddish when first exposed to the air becoming reddish after exposure. The root system consists of a strong tap root and well developed lateral roots. The alternate, pinnate leaves are medium (Ganguli, 2002).

2.8.1.4 Distribution:

Neem is widely distributed throughout South East Asia and West Africa and part of Central America (Stoll, 2000). Neem was introduced to Sudan in the 20 century. The first tree were planted at Shambat in 1916, today trees are spread in towns and villages along the Blue and White Niles, irrigated areas of Central Sudan, Kordofan and Darfur (Schmutterer, 1969).

2.8.1.5 Ecology:

The Neem trees is famous for its drought resistance, normally it thrives in areas with sub-arid to sub humid conditions with an annual rainfall between 400 and 1200 mm. It can grow in regions with an annual rainfall 400mm. but in such cases it depends largely on the ground water levels. Neem can grow in many different types of soil, but it seems to develop best on well drained, deep sandy soils.

2.8.1.6 Active ingredients:

The Neem tree produce a compound of many active ingredients called Azadirachtin and it is a triterpenoid compound, which influences the hormonal system, feeding activity, reproduction of insect. Azadirachtin has low mammalian toxicity. It degrades rapidly in the environment and has low side effects on non-target species and beneficial insects. Seeds of the Neem tree contain the highest concentration of Azadirachin. Salanin inhibits the feeding of insect pests, Nimbin and Nimbidin showed antiviral effects (Ganguli, 2002)

2.8.1.7 ChemicalCompound of the Neem tree:

Extracts of various parts of the tree were studied by many chemists who isolated many different compounds. Most of the known active compounds belong to the group of titer penoids (Schmutterer, 1990). Azadirachtin and Solanin are the most important constituents of neem seed kernel composition, other active compounds in the seed kernel are Salanin, Salanol, Acetate, Nimbin and Deactly nimbidin (Jacobson, 1989)

2.8.1.8 Mode of action:

Neem acts as insects feeding deterrent and growth regulator, the treated insects usually cannot molt to its next life stage and dies,,and Azadirachtin is chemically similar to ecdysone responsible for triggering molts. It also acts as repellent when applied to plant and does not produce a quick knock down and kill (Schmutterer, 1990). Also Neem has some systemic activity in plants, itis most effective on growing immature stages. Adults are not killed by the growth regulator properties of Azadirachtin, but mating and sexual communication may be disrupted which results in reduced fecundity (Schmutterer, 1990 and Pedigo, 1999)

2.8.1.9 Uses of Neem in pest and disease control:

Neem is deemed very effective in the treatment of scabies, although only preliminary scientific proof exists which still has to be corroborated. In treating infestations of head lice in humans, neem was very good for treating worms. In the traditional medicine neem trees originated on the Indian subcontinent. The neem twig is nature’s tooth brush to over 500 million people daily in India alone. Herbal medicine is the oldest form of therapy practiced by mankind and much of the oldest medicinal use of plants seems to have been based on highly developed ‘dowsing instinct’ (Schmutterer, 2002). Siddig (1993) reported from Sudan that neem seed water extracts at1Kg/1Liter of water repelled foliage pest, of potato including *B. tabaci*, *Aphis gossypii* and *J. lybica* and yield increased to 5 ton/ ha. Mohammed (2002) reported that neem seed showed good performance against *A. gossypii*, *B. tabaci*, and *J. lybica* on Okra. Dawood (2001) reported that Neem water extracs at 1Kg/liter water reduced the number of onion thrips by 63.5% under the field condition.

2.8.2 Argel (*Solenostemma argel*) :

Kingdom: Plantae

Class: Magnolopsida

Order: Gentianales

SubFamaily: Ascleptadoideae

Famaily: Apocyanaceae

Genus: Solenostemma

Species: argel

Scientific Name: *Solenostemma argel* (Del) Hayne

English Name: Hargal.

2.8.2 .1 Description:

It is an erect perennial shrub that reaches up to 1.5-2 feet in height with numerous branches carrying opposite decussate leaves; the leaves lanceolatate to oblong –ovate, with acute or sub-acute apex, and cuneate base, the leaf petiole is thick. Fruits are solitary folliles, thick, ovoid, lanceolate, acuminate at the apex and they are very hard with dark purple coluor. Seeds are turgid, ovoid, they are minutely tuberculate bearing an apical tuft hair (Elkamali, (1991).

2.8.2. 2 Distribution:

Solenostemma argel is a desert plant, which is of wide spread in central and northern parts of the Sudan, Egypt, Libya, Chad, Algeria, Saudi Arabia and Palestine. However, Sudan is regarded as the richest source of this plant (Orange, 1982).

2.8.2 .3 Locality:

Solenostemma argel grows wild or cultivated in north Sudan, in the area extending from Dongola to Barber, whose Capital town is Ubo Hamad, is famous for Argel production and wild collection (Elkamali, 1991).

2.8.2.4 Chemical constituents of Argel:

Elkamali (1991) conducted a photo chemical screening of Argel constituents of the leaves, stem and roots at the pre- flowering and flowering stages. Results of photochemical screening showed the presence of a number of chemical groups (Flavonoides, tannins, sterols triterpens, and saponins), the major constituents were saponins.

2.8.2.5 Insecticidal activity of *solenostemma argel* :

Hag–Eltayeb (2005) reported that, argel aqueous extract was effective in control of the larvae of mosquitoes *Culex spp* and *Anopheles spp*. under laboratory conditions. Also Argel water extract when tested under laboratory conditions against faba bean beetle, *Buruchidius incarnatus* at 2.5%, 5%, and 10 %, gave 60.1%, 66.7% and 75.8% mortality of the adult insects, respectively (Mohamed, 2004).

2.8.3 Usher(*Calotropis procera*)Ait

Kingdom: Plantae

Order: Gentianales

Famaily: Apocynaceae

Genus: Calotropis

Species: procera

Scientific Name *calotrops procera*

English Name: Usher

2.8.3.1 Description

Calotropis procera is a spreading shrub, or a medium-sized tree reaching 2.5 to 6 m in height. It has a deep taproot, 3-4 m deep, and a secondary root system with woody lateral roots that may rapidly regenerate adventitious shoots when the plant is injured. The stems are crooked and covered with a fissured corky bark. The grey-green leaves are 15- 30 cm long and 2.5-10 cm broad and have a succulent and waxy appearance, hence the name procera, which means wax in latin (Orwa *et al.,* 2009). The flowers are pentamerous, small, cream or greenish white at the base and purple violet at the extremity of the lobes. The fruit is a fleshy and inflated, up to 10 cm or more in diameter (Orwa *et al*., 2009; Kiew, 2001). *Calotropis procera* is a multipurpose tree. The stems yield a fibre useful for making ropes, bags, nets and paper (Orwa *et al*., 2009). The seeds contain white silky floss that is a potential silk replacer (Batello *et al.,* 2004). The wood is valuable as a timber and fuel (Orwa *et al.,* 2009; Kiew, 2001). The milky sap (latex) is renowned for its ethno-medicinal properties (Batello *et al*., 2004; Iqbal *et al.,* 2005) and as a food, particularly as a coagulation agent for cheese making in West Africa (O'Connor, 1993). Calotropis yields 90 t of biomass twice a year and is a potential source of renewable energy (Parsons 2001).Calotropis is also used as fodder. Young pods, senescing leaves and flowers can be fed to goats, camels, and sheep (more rarely to cattle) in times of scarcity. The latex contains toxic components that may be harmful to livestock.

2.8.3.2 Distribution:

Calotropis procera is naturally spread in Southern Asia, and Arabian Peninsula. The plant has naturalized in Australia, Americas and west India. It spread on an aca expanding from north western Africa .it quickly becomes established in open habitats with little competition, along degraded roadsides, lagoon edges and in overgrazed native pastures and rangelands (Orwa *et al.,* 2009*).* When Calotropis is damaged, it readily develops suckers from the roots (Parsons and Cuthbertson 2001*).* Calotropis seeds are spread by wind and animals and may be transported long distances in flood waters (Parsons and Cuthbertson ,2001*).*

2.8.3.3 Anthelmintic effects:

Different extracts of *Calotropis procera* leaves were evaluated for in-vitro Anthelimonitic activity against Indian earthworms *Pheritima posthuma*. The ethanol extracts of the different parts of *Calotropis procera* showed IC**50** values ranging from 0.11 to 0.47 mg/ml against *P. falciparum* MRC20-chloroquine sensitive, and from 0.52 to 1.22 mg/ml against MRC76- chloroquine -resistant strains, flower and bud extracts being the most active. Although 220-440 times less effective than chloroquine, the crude ethanol extract of *Calotropis procera* leaves have been screened for its larvicidal activities against *Musca domestica*. The third instar larvae of housefly were treated with the different concentrations of the extract by dipping method for 48 h. The LC50 values of the extract of *C. procera* leaves were found to be 282.5 mg/l.

2.8.4 Black Pepper (*piper nigrum*):

Kingdom: Plantae

Class: Magnoliids

Order: Piperales

Famaily: Piperaceae

Genus: Piper

Species :*nigrum*

Scientific Name: *Piper nigrum*

Out of 1000 species of piper, *P. nigrum* is the most important cultivated species due to its economic value (Bhat *et al*., 1995). Geographically, it is confined to Western-Ghats of South India (Nair –Gupta , 2003). *P. nigrum* had been found in vast altitudinal regions and showed great adaptability to a wide range of environmental conditions which led to inter-species diversity (Howard, 1973). “Black-pepper” as its generalized name is due to the color of the peppercorn. It is considered as the “king of spices” due to its trade in the international market (Srinivasan, 2007; Mathew *et al.,* 2001). *P. nigrum* is reputed in the local system of medicine of India, Latin America and West-Indies for its multidimensional medicinal properties (Scott., *et al*., 2008) Piperamides extracted from *P. nigrum* had shown insecticidal activities (Scott *et al.*, 2005). Caryophyllene extracted from *P. nigrum* showed anesthetic activity (Santra *et al*., 2005). Nero idol is a very famous secondary metabolite of *P. nigrum*, used to control mites. Another important component of pepper volatile oil is pipene, which is a famous odorants (Jayalekshmy *et al*., 2003). Black-pepper is anti-microbial (Dorman and Deans, 2000), anti-mutagenic (EI-Hamas *et al.,* 2003), a free-radical scavenger (Gulcin, 2005), immunostimulator, anti-tumor (Sunila and Kuttan, 2004), anti-depressant (Lee *et al.*, 2005), anti-apoptotic (Pathak and Khandelwal,2007),(Panda and Kar, 2003), hepatoprotective (Koul and Kapil, 1993), immune-stimulator (Pathak and Khandelwal, 2009), anti-diarrheal and anti-spasmodic (Bajad *et al*., 2001). *Piper nigrum* (black pepper), considered the "King of Spices" because of its economic importance and its ubiquitous culinary presence, had its transcriptome data from leaves and roots recently described (Gordo *et al.*, 2012; Joy *et al*., 2013).

2.9 Spinosad:

Spinosad is the first active ingredient proposed for a new class of insect control products, the Naturalytes. Spinosad is derived from the metabolites of the naturally occurring bacteria, *Saccharopolyspora spinsa.* Spinosad has been shown to be highly active on insects including species from the orders Lepidoptera, Diptera, Hymenoptera, Thysanoptera, and a few Coleoptera. Spinosad may be used to control pests in both agricultural and horticultural environments, and alsoin greenhouses, golf courses, gardens, and around homes. Spinosad has been developed to provide rapid control of Lepidoptera and other pests with minimum disruption of beneficial insects and other non- organisms. Because it is highly effective, only very low use rates are required to achieve efficacy. These attributes permit to many users an opportunity to implement integrated pest management tools for the first time. Due to its low effective use rate, the safety to the environment, the safety to mammals, and safety to beneficial insects, spinosad was registered under the US EPA,s reduced risk program. Spinosad was also awarded the Presidential Green Chemistry Challenge Award during 1999. This award recognizes the unique contribution of spinosad and also highlights Dow Agro Sciences commitment to producing safer and more effective products for insect control.

2.9.1 The Spinosad story:

During the last decades, companies including the Dow Chemical Company and Eli Lilly and Company began to actively look for naturally occurring pest control products. As a result of these efforts, a scientist from the Natural products division of Eli Lilly while vacationing in the Caribbean in 1982 visited abandoned rum still and collected several soil samples. These samples were returned to the laboratory to determine the presence of biological activity. Three years later the fermentation products from these samples were shown to have insecticidal activity. By 1986 Eli Lilly's scientists identified the organism producing the biologically active substances. They determined that this was a new species of actinomycete products division. (Mertz, and yao1990, Thompson *et a.*, 1997 and Crouse, 1998).

2.9.2 Symptomology:

Sensitive insects exposed to Spinosad exhibit unique symptomology that is typified by a general paralysis accompanied by loss of body fluid resulting in flaccid paralysis. Under close examination, minute tremor of the mandibles and crochets can be seen. The onset of paralysis is quite rapid for a biological material. The length of time required was 81 minutes before 50 percent of third instar *Heliothis virescens* larvae treated topically with 10mg of technical material failed to respond to a hot needle probe. That can be compared to 25 minutes for cypermethrin treated larvae. However, intoxicated insects remain on the plant for one to two days without feeding; whereas, insects treated by excitatory compounds, such as pyrethroids or organophosphates, tend to fall off the plants more rapidly.

2.9.3 Mode of action:

In insect, the mode of action of Spinosad is associated with excitation of the insect nervous system (Salgado 1998). Spinosad uniquely alters the function of nicotinic and GABA-gated ion channels (Salgado 1998, Watson, anunpublished data), in a manner consistent with the observed neuronal excitation. However, spinosad does not interact with known binding sites for other nicotinic or GABAergic insecticides such as neonicotinoids, fiproles, avermectins and cyclodiens. These data indicated that spinosad acts through a unique insecticidal mechanism (Salgado1998).

2.9.4 Registrations:

Spinosad has been approved for use by registration authorities in more than 30 countries and the first registrations were granted during late 1996 and early 1997 for cotton, almonds, vegetables, and turf and ornamentals. Since that time, many additional crop and non-crop uses have been approved worldwide, ranging from Australian cotton to Japanese crucifers to Mexican tomatoes to Chilean stone fruit to Israeli melons. Spinosad products have found utility for pest management for a wide variety of crops, and in the U.S. alone use has been approved on more than 150 crops. In addition to crop uses, Spinosad is also approved for non-crop uses on turfgrass and ornamental plants, for livestock pest control, and fire ant control.(Salgado1998).

2.9.5 Reduced risk classification by Environmental Protection Agency (EPA)

Spinosad has been classified by U.S. Environmental Protection Agency (EPA) as a reduced risk pesticide product. This classification affords preferential registration and expedited label expansions to select products that meet the Agency's stringent criteria and pose less risk to public health and the environment than available alternatives. Spinosad has been classified by EPA as a reduced risk insecticide product because of its: Low acute mammalian toxicity, Low toxicity to fish and wildlife Compatibility with integrated pest management and lack of beneficial insect disruption

2.9.6 Ecotoxicology:

Spinosad is not acutely toxic to terrestrial birds and wildlife or to fish and most aquatic invertebrates. Laboratory studies indicate that some free-swimming and sediment-dwelling aquatic invertebrates may be sensitive to long-term exposure to spinosad. Under field conditions, this sensitivity may be mitigated by the rapid dissipation of spinosad which occurs from the water column as well as sorption and binding of that small portion of residues organisms (Salgado1998).

2.9.7 Environmental fate:

2.9.7.1 Fate in soil:

Spinosad degrades readily in the soil environment and is non-persistent. Primary mechanisms of degradation are sunlight photolysis and microbial breakdown. Under field conditions, Spinosad dissipates rapidly from soil surfaces with observed half-lives of less than 1 day (Hale*, and Portwood* (1996).

2.9.7.2 Fate in water:

In natural water systems Spinosad rapidly dissipates, with the primary route of degradation involving sunlight photolysis. A water column half-life of less than 1 day has been observed in artificial pond systems under outdoor condition (Saunders, 1997).

2.9.7.3 Fate in plants:

Residues of Spinosad present on plant surfaces dissipate at a moderate-to-rapid rate, primarily due to sunlight photolysis. Dissipation half-lives of 2 to 16 days have been observed for residues on leaf and fruit surfaces, the rate dependent on the amount of sunlight received and degree of shading (Saunders, 1997).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Main materials and Equipments used in the study:

Materials:

The main materials used in this study were:

Muslin cloths, Filter papers, Cotton, Distilled water, Sand, Soap, Funnel, and, Neem leaves Argil, Usher, Pheromones, Seed of Black Pepper and Trapping strip.

Equipment:

Also, the equipment used in the study included Plastic and Glass cages, Hand Sprayer, Petri dishes, Brushes, Gloves, Hand Lenses, Glass Pipette, Mobile Camera, Traps, Sensitive balance, Measuring cylinder and Rotary evaporator.

3.2 General Surveillance of the fall armyworm, *Spodoptera, frugiperda* in Sudan States:-

According to the latest records of the Plant Protection Directorate, concerning the infestation by *Spodoptera frugiperda* (FAW) in Sudan, a survey was made for "Five Weeks" during September – October 2018, in a number of States. The survey was carried out to determine the infestation levels of the (FAW) and the main host plants, and it included 15 sites in 9 States these are Northern State: 1 site; Khartoum State: 4 sites; Gazira State: 1 site; Sinnar State: 2 sites; Gadarif State: 2 sites, Kassala State: 1 site, Blue Nile state:1 site, South kordofan: 2 sites and West Darfour State: 2 sites). The positions of the survey sites were determined by using GPS.The survey was conducted in the open fields at each site.

Pheromone Traps (Russell IPM Traps, Sudan) were used, and each trap was provided with a “Trapping strip” of the pheromone (PH 569IPR) **(**Plates No.1 & 2) which lasts for one Month. Traps were hanged at approximately 1.5 meters above ground, and were distributed in the fields at a density of one trap for every 0.5 –2 feddan of crop, according to the area (Plates No.3&4). The traps were checked twice per week, and the numbers of adult moths caught per trap / per day / per week were recorded. Information collected when checking pheromone traps were carefully recorded, so as to be shared and used for FAW Early Warning System (FAWEWS) of FAO. Moreover, the number of infested cultivated crops and wild host plants of FAW were recorded. Also, leaves and fruits infested with FAW were collected from host plants and kept in the laboratory to observe their suitability as host plants.

Plate No.1 A trapping strip

Plate No.2 A Pheromones

Plate No.3 A PhermoneTrap

Plate No.4 Postion of A Pheromone Trap in the field

3.3. Damage of Fall army worm in Khartoum State in 5 Sites

To determine the damge of the FAW in Khartoum State, regular surveys and visits were made during a period of 3 months (Octob-Nov- December 2018) to the main 5 sites determined for FAW study in Khartoum State. These are: Shambat, Alfaki-Hashim, Kafuri, Tuti and Al-Shehainab in Omdurman (Figure No.1). During the study period, pheromone traps were allready fixed in Maize field in each site to monitor the presence of the FAW in the site. The regular visits were made at an interval of 4 weeks during the study period. In each site, 50 maize plants were randomly sampled to assess the proportion of plants infected and also precentage of damge caused.

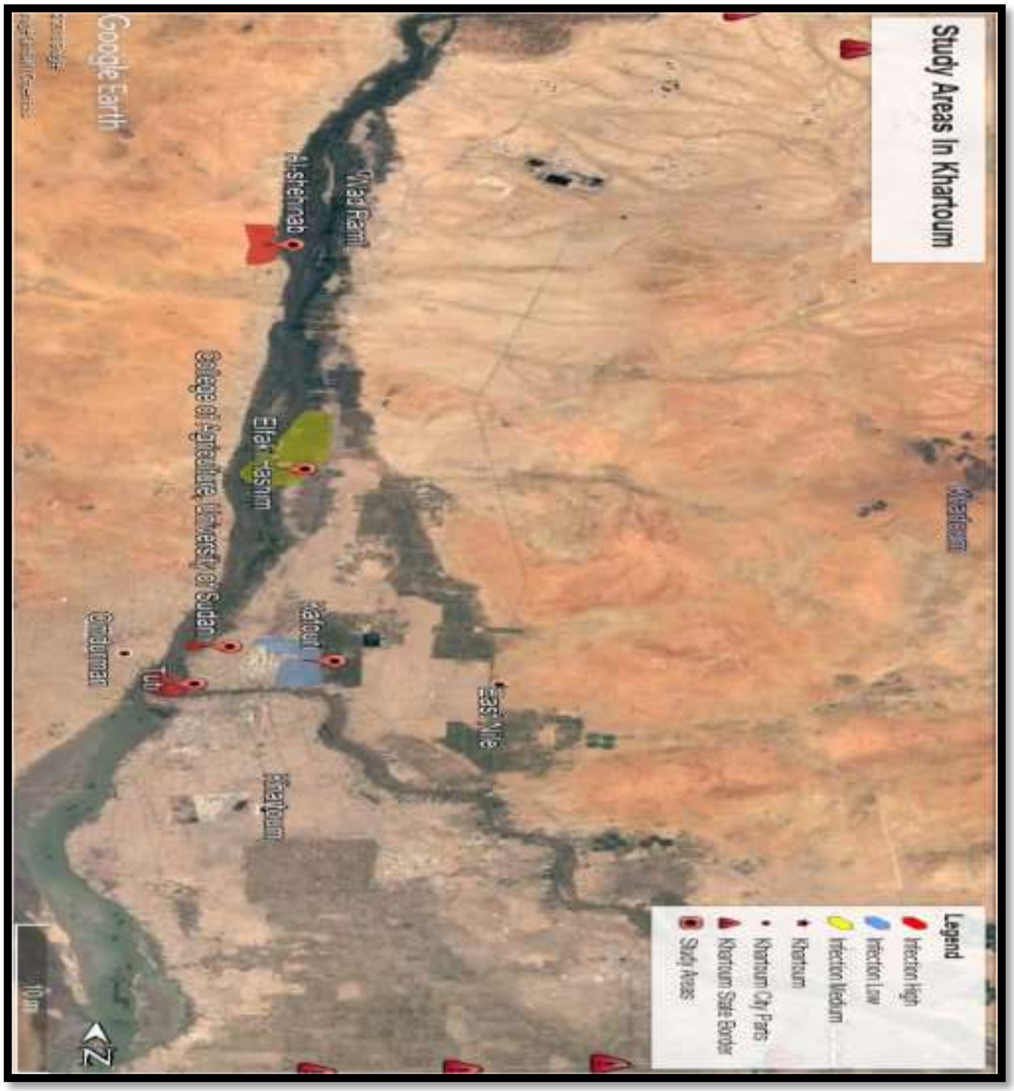


Figure No.1 Study Sites of FAW in Khartoum State

3.4 Studies on the biology and ecology of fall armyworm, *Spodoptera frugiperda* :

3.4.1The rearing of insects :

During the period from September 2018 up to the end of August 2019, regular surveys were made in the maize fields infested with FAW (*S. frugiperda*) at the Agricultural farms in Shambat, to determine the life cycle and annual generations of the insect under laboratory conditions. Infested Maize crops were collected and brought to the laboratory. FAW Larvae were collected from the infested plants and reared in plastic cages (29×20 ×20 cm) under laboratory conditions of a temperature range of 21- 30 ^{0}c and 65±5 % RH. After adult emergence, ten pairs, each of a male and a female, were released in separate cages. The adults were fed on 10% sugar solution soaked on cotton pads offered in small plastic caps inside the cages and replaced daily. The pre-oviposition, oviposition and post-oviposition periods and number of eggs laid by each female were recorded. The eggs were collected and kept in a circular insect breeding dish and were examined at intervals of 12 hrs for hatching. After hatching, Thirty larvae (n = 30) were reared individually and fed on fresh maize leaf bits which were changed daily. The number of larval instars, larval and pupal durations and longevity of emerging adults and sex ratio were recorded. Annual generations of the FAW were also observed. These procedures of rearing adults and larvae were repeated regularly during the observation periods on the FAW development during the whole year.

3.5 Collection and identification of the natural enemies of (FAW) in Khartoum State

These studies were made during the period from August up to October 2018 at Shambat study site. Regular collection of maize plants infested with FAW were collected. Each Week, (Fifty) plants were collected randomly from the fields and brought to the laboratory and examined carefully. All FAW stages found (i.e. eggs, larvae and pupae) were collected and examined. Also, all natural enemies found (weather parasites, predators or pathogens) were recovered and preserved in 70% Alcohal for further mounting and later identifications. Identifications of the natural enemies found were made by the Staff of the Department of Plant Production of the Collage of Agricultural studies Shambat, and also based on the paper by Molina-Ochoa, 2004) and other Taxonomy texsts.

3.6. Efficacy of an extract of a Mixture of Pathogenic Micro-organisms on the FAW.

During the regular survey at Alshehainab study site in Omdurman, it was noticed that large numbers of FAW were dead due to an infection by micro –organisms (wheather bacteria, fungi, nematods, or viruses). Micro-organism (which are shown in Plates No.5& 6). Accordingly, all these dead larvae were collected and brought to the laboratory. Then all larvae were ground to a fine powder, mixed with a liter of water and left for 24 hours, then the mixture was filtered and 5 liters of water was added then the mixture solution was sprayed on specifc area (o.6 feddan) infected by FAW at Alshehainab Site. After 24 hours, and then each week 15 plants were chosen randomly from the sprayed area and a numbers of dead FAW larvae, effect on egg masses and the natural enemies found were counted. Also, effect on newely emerged larvae was recorded .This was made for 4 weeks according to the FAW Early Warning System (FAWEWS) of FAO.

Plate No.5 A FAW infected with A fungus9

nmnxx

Plate No.6 A FAW infected with Avirus (Sourse CABI)

3.7 Laboratory trials for the control of the fall army worm *Spodoptera frugiperda* using plant extracts:

3.7.1 Plant Species used in the study:

Extracts of four plants, Neen (*Azadirachta indica*), Black piper (*piper nigrum*), Usher (*Calotropis procera*) and Argel (*Solenostemma argel*), were chosen for application against immature stages of S. *frugiperda*. Neem seeds and Usher leaves were collected from Shambat area, and Argel leaves and black piper were obtained from the local market, all were washed and dried under laboratory condition for 48 hrs. Then, they were ground to a fine powder by an electric blender (Moulinex), and the powders were kept in tight containers, to be used later.

3.7.2 Preparation of the plants extracts :

Neem seeds, Black pepper seeds and Usher powder extracts were made by using (Ethanol) at the Environment and Natural Resources and Desertification Research Institute (ENRDRI). Extraction was made according to the method described by Sukhdev *et al.*, (2008). Samples of each plant powder were soaked with absolute Ethanol. Extraction was carried out for three days, with daily filtration and evaporation of the solvent under reduced pressure using rotary evaporator apparatus (PlateNo.7). Samples were allowed to air in an evaporating dish till complete dryness. A stock concentration was prepared for each extract and serial dilutions were made to prepare 4 different concentrations for the bioassay treatments.

Weight of extract obtained / weight of plant sample X 100.

Yields of *Calotropis procera, Piper nigrum* and Azadiractina indica are (4.03, 6.75 and 2.97% respectly.

3.7 .3.Preparation of the aqueous extracts

Extraction was also carried out according to the method of Sukhdev *et. al.* (2008). With slight modification. The extract was prepared by mixing 2.5gm of the leaves powder in 10 liters of water, and the mixture was left for 24 hrs. Then, also several dilutions were made to prepare 4 different concentrations (ie, 10%, 25%, 50%and 75%forbthe bioassay tests.

3.7.4 Laboratory bioassays on the Larvae *Spodoptera frugiperda:*

Four groups, each of 15 recently hatched larvae of (FAW), were placed in Petri-dishes, each contained a piece of fresh maize leaf, previously immersed for 5 seconds in each of the different concentrations (10, 25, 50 and 75%) of each extract. Another group, of 15 larvae, was used as a control with each concentration, and was placed in a Petri- dish, contained fresh maize leaf, treated with Ethanol, and with distilled water with Argel extract. A group of 15 larvae was added to each replicate, and was treated with the recommended dose of a standard pesticide, Spinosad [Tracer Spinosad, Chemimport Company Ltd, Sudan]. Each treatment was replicated three times. Criteria of larval mortality: the larval colour changes from brownish to dark, then larvae become sluggish, and finally died.

Plate No.7 Soxhlet and Rotary evaporator

3.7. 5 Experimental Design

The experiments were conducted using a Randomized Complete Block Design (RCBD).

3. 7.6. Statistical analysis

The data obtained were transformed using ($\sqrt{x}$+0.5). Analysis of variance (One Way ANOVA) was applied for data analysis using SPSS Program (version20) and means were separated using Tukey test.

CHAPTER FOUR

4. RESULTS

4.1 General Surviellance of Fall armyworm *S. frugiperda* in Nine States in Sudan

As indicated, the survey carried out in Sudan covered 15 sites in Eight States in the Country (Table No. 1). The results of the survey showed that, infestation by *Spodoptera frugiperda* (FAW) has a wide distribution in all States, and indicated that, Maize, Tomatoes, Ubo Sabeen, Sorghum and Millet, represent the main host plants of the (FAW) in all survey sites (Table No.1 .). Also, total areas surveyed, areas affected, No. of moths collected / trap / week and levels of infestation determined after inspection of most of the sites are shown in Table No.2). Severe damage (up to 100%) was observed on tomatoes (*Solanum lycopersicum)* at Elshehainab site and on Maize, millet and Ubosabeen at Shambat in Khartoum State. (Plate No.8) Also, high infestation (83.3%) was recorded on Maize in Singa. In Elgazira State, the number of captured moths was 37.5/ trap/ week, however, the damage observed was moderate and only observed on maize. On the other hand, slight infestation was recorded on Sorghum and millet in Algaba and Al-Genaina (AL- kilo90), respectively (Figure No.2).

Table No.1 .The Surveyed Sites of *S. frugiperda* in Nine States in Sudan

State	Site	Main Cultivated crops	Latitude/Longitude
1. Northern	Al-ghaba	Maize	18.04.58 N / 30 30.57 E
2. Khartoum (Site 1)	Shambat	Maize, Millet	153949.0 N / 32 5319.0 E
2. Khartoum (Site 2)	Kafuri	Ubo Sabeen, Maize	16 00 56.6 N / 32 34 14.3 E
2. Khartoum (Site 3) (Omdurman Locality)	Al-Shihainab	Tomatoes, Maize, Sorghum	16 03 30.7 N / 32 01 57.0 E
3. Al Gazira	Um Algoura	Maize	133 44 49 N / 33 3601 E
4. Sinnar (Site 1)	Singa	Maize , Sorghum	13 15 00 N / 33 93 33 E
4. Sinnar (Site 2)	Sinnar	Maize , Sorghum	13 56 00 N / 33 93 06 E
5. Gadarif (Site 1)	Al-Faw	Sorghum, Sunflowers	1414718N / 2618.44E
5. Gadarif (Site 2)	Al-Fashaga	Sorghum, Sesame, peanut	1319.26N / 34362.8 E
6. Kassala	Kassala	Sesame, Sorghum	15 25 59 N / 36 21 17.6 E
7. Blue Nile	Damazin	Sorghum	11 45 59 N/ 34 20 59 E
8. South Kordofan (Site 1)	Kadogli	Maize	1319.26.4 N / 3436 2.8 E
9. South Kordofan (Site 2)	Al-Abbasia	Sorghum	14. 24 .9. N / 35 20013E
9. West Darfur (Site 1)	Al-Genaina (Alkilo 90)	Sorghum, Millet	225032N / 1304966E
9. West Darfur (Site 2)	Al-Genaina (Nabgaya)	Millet	2256739N /1305657E

Table No .2. Survey and Affected Areas in some sites in Nine States in Sudan, with infestation rate and No. of Moths collected / trap / week

Site	Survey Area/feddan	Affected Area/feddan	No.of moths / trap / week	Infestation Rate & Percentage of area affected
1. Kadogi	10 feddan	3 feddan	1.5	Moderate (30%)
2. Damazain	5 feddan	5 feddan	10	High (100%)
3. Elshehinab	2 feddan	2 feddan	17.5	High (100%)
4. Alghaba	2000.189 feddan	395.376 feddan	0.25	Moderate (19.76%)
5. Gadaref	3000 feddan	127.5 feddan	1.5	Slight (4.25%)
6. Elgazira	900 feddan	300 feddan	37.5	Moderate (33.3%)
7. Al-Genaina	97.86 feddan	6.3 feddan	1.5	Slight (6.43%)
8. Singa	3 feddan	2.5 feddan	1.5	High (83.3%)
9.Kassala	3Fegddan	2.5feddan	1.5	High (83.3%)

Plate No.8 (A)

Plate No.8 (B)

Plate No.8. Signs and damage symptoms of FAW on Maize Leaf (A & Heart(B)

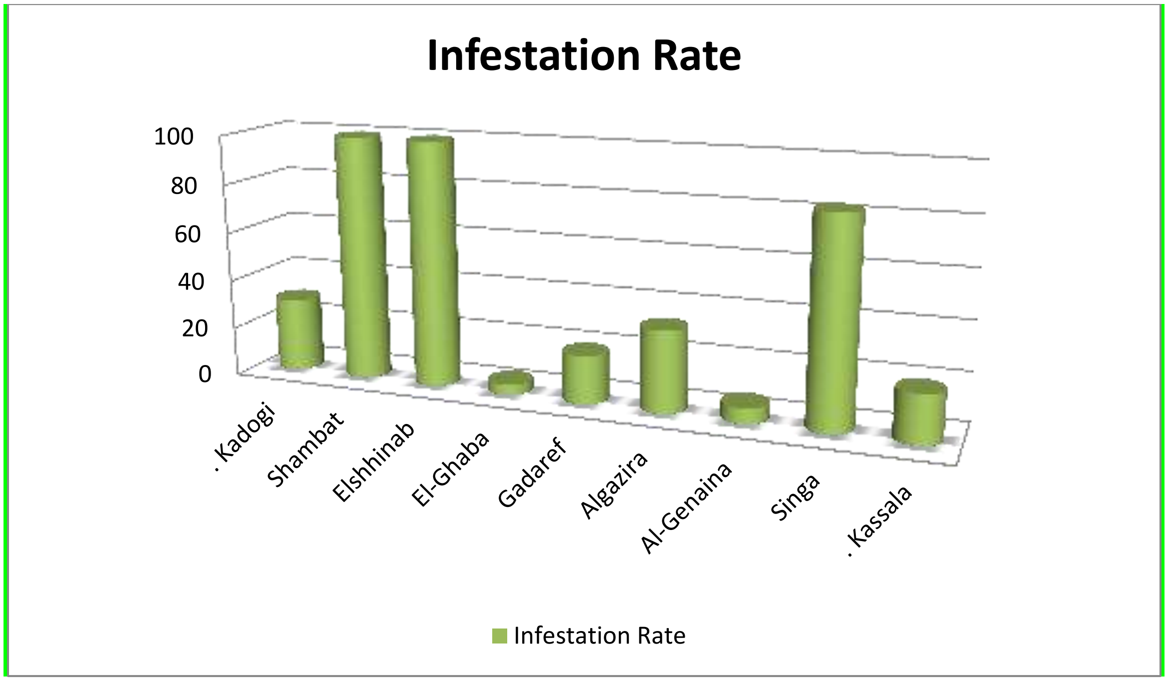


Figure No.2 Percentage of "FAW Infestation Rates on Maize in Nine Sites in Sudan 2018

4.2. Damage on fall army worm in Khartoum State:

Table No. 3 and Figure No.3 shows that there was significant difference between the Five Study Sites in Khartoum State. The Mean percentage of damage in December and November was significantly higher than October. Mean percentage of damage in Shambat, Touti and Alshehainab were significantly higher than Kafouri and Alfaki hashim. The same trend was observed in November and December, percentage of damage in Alfaki-hashim and Kafouri was significantly less than Shambat, Touti and Alshehainab.

Table No. 3 Mean percentage off damage *of Spodoptera frugiperda* at the Five Study Sites in Khartoum State (October – December 2018)

		Mean percentage (%) of Damage		
Site	N0.of Plants examined	October	November	December
Touti	50	50(7.1)	100(10.02)	100(10.02)
Shembat	50	52(7.3)	38(6.2)	100(10.02)
AlfakiHashim	50	36(5.9)	52(7.3)	70(8.2)
Kafouri	50	38(6.2)	35(5.8)	36(5.9)
Alshehainab	50	38(6.2)	74(8.6)	100(10.02)
LSD		(0.9)	(1.2)	(1.3)

Means followed the same letter(s) are not significantly different at $p \leq 0.05$means between brackets are transformed by($\sqrt{x+0.5}$).

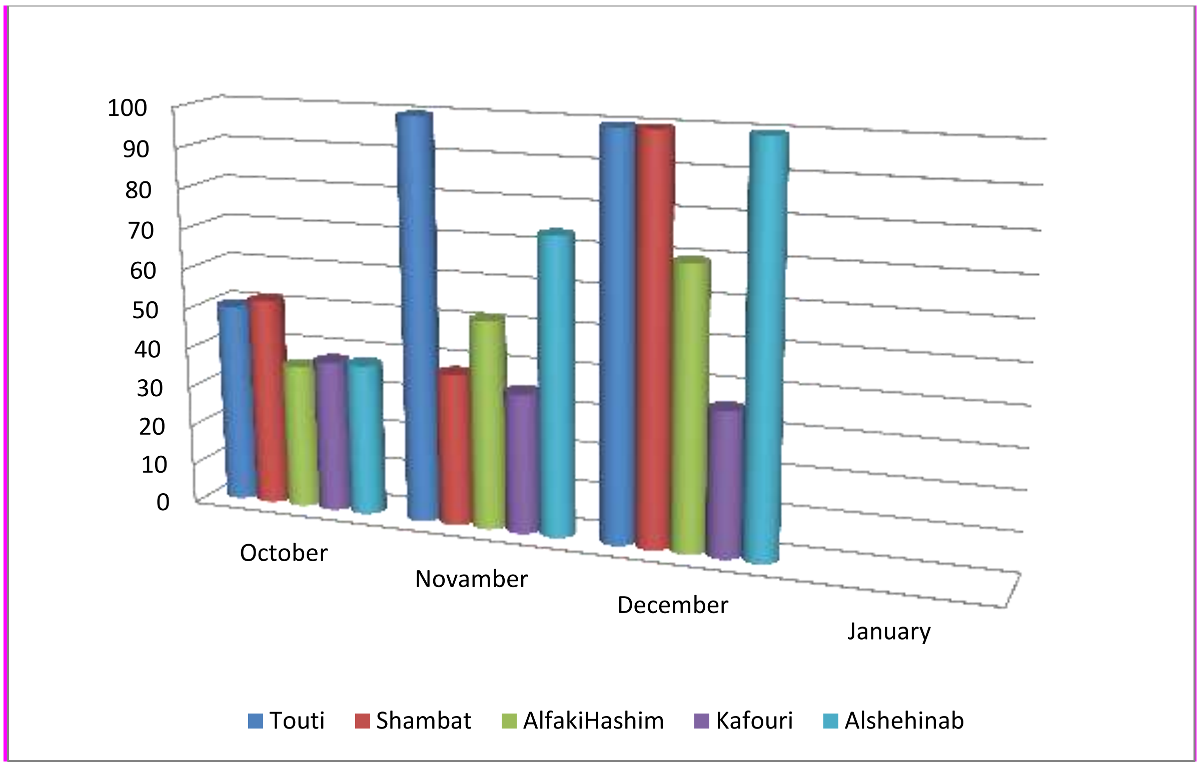


Figure No.3 Mean Percentage of damage of the FAW *Spodoptera frugiperda* in Five Sites in Khartoum State

4.3. Studies on the biology and ecology of fall armyworm, *Spodoptera frugiperda:*

The present study involed recording the biological parameters observed during development of the FAW for one year (from begining of September 2018 – up to the end of August 2019). The results of the study are shown in Tables No. (4 & 5).

In these results, the range of eggs laid by a female was (890 – 1169) eggs (Plate No .9) the egg incubation period ranged between (3-13)days, the larval duration ranged between (13-50) days and the pupal duration ranged between (7-20) days Plate No.9), under a temperature ranged between (21-30) ^{0}c and a Relative Humidity of (65 ± 5%). The longevity of adults ranged between 1-20 days, (Plate No.10), and the full life cycle range was about (24-100) days.

The regular observations of the (FAW) made in the field and in the laboratory showed that, its reproduction contineued during the whole year round. Under normal laboratory conditions, Six generations of the FAW were recorded during its development wihin Twelve monhs (Table No. 5).

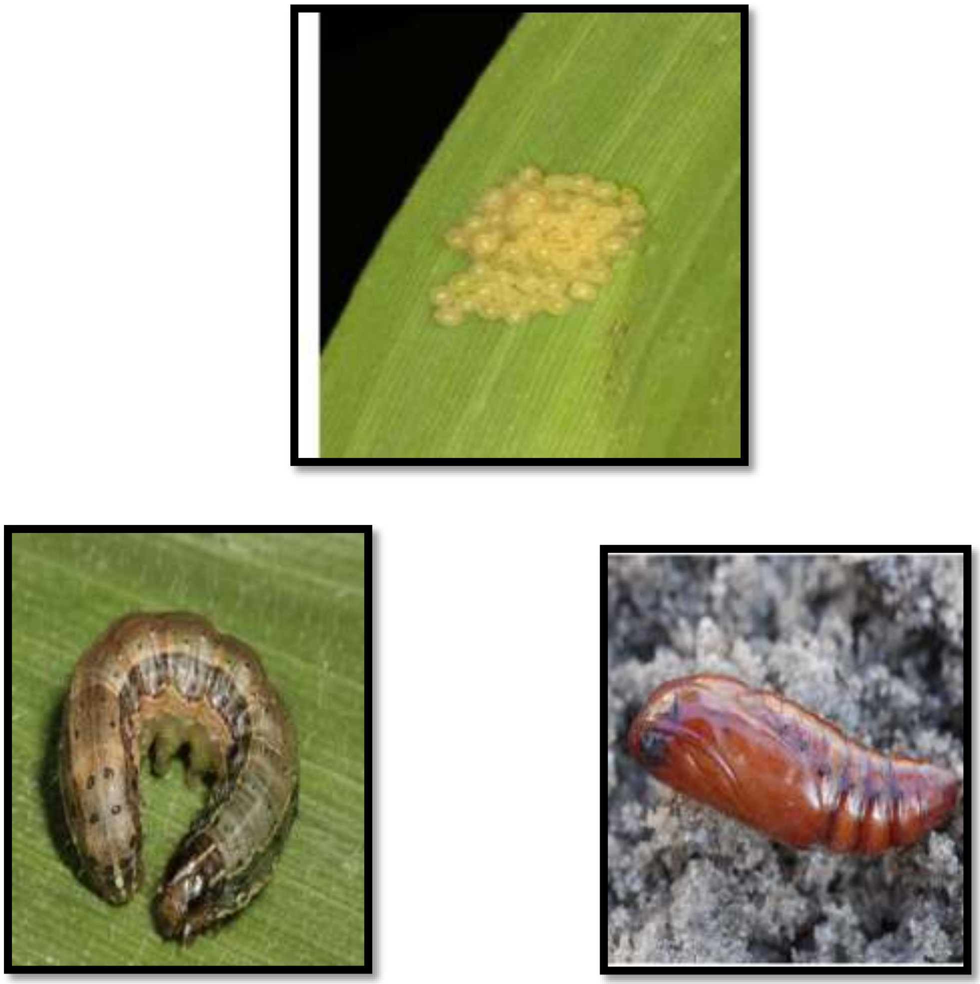
Table No. 4 The Biological Parameters of *Spodoptera frugiperda*

(Recorded During One Year, under Laboratory Conditions)

Stage	**Range (Days)**	**Mean ± SD**
Pre-oviposition Period	3.00 – 4.00	3.6 ± 0.49
Oviposition Period	2.00 – 3.00	2.8 ± 0. 40
Post-oviposition Period	4.00 – 5.00	4.3 ± 0.46
Female Fecundity (No. of Eggs)	890.00 - 1169	1029.8 ± 139.5
Egg Hatchability (%)	90% - 95%	92.5 ± 2.5
Adult Male Longivity	7.00 – 9.00	8.20 ± 0.75
Adult Female Longivity	9.00 – 12.00	10.80 ± 0.87
MaleTotal Life Cycle (Egg - Adult)	24 – 54	39 ± 15.00
Femal Total Life Cycle (Egg – Adult)	26 – 57	41.5 ± 15.5

Table No. 5 The Six Generations of FAW (*Spodoptera frugiperda*) recorded during a period of Twelve Months under Normal Laboratory Conditions

Generations	Month	Incubation Period Range (Days)	Larval Duration Range (Days)	Pupal Duration Range (Days)	Adult Longevity Range (Days)	Total Life cycle Range (Days)	Normal Laboratory conditions	
							Temperature °C	Humidity %
1st	9,10	3-5	13-24	7-12	1-13	24-54	27	65
2nd	10,11	3-6	15-39	7-15	2-15	40-74	25	68
3rd	12, 1,2,3	3-10	25-50	18-20	1-20	47-100	21	66
4th	4,5	8-13	29-40	15-20	1-12	53-85	22	70
5th	6,7	3-5	13-30	11-14	2-20	29-69	23	71
6th	7,8	3-5	15-25	7-10	1-15	26-55	30	69



Plat No.9 Eggs, larva &pupa of FAW

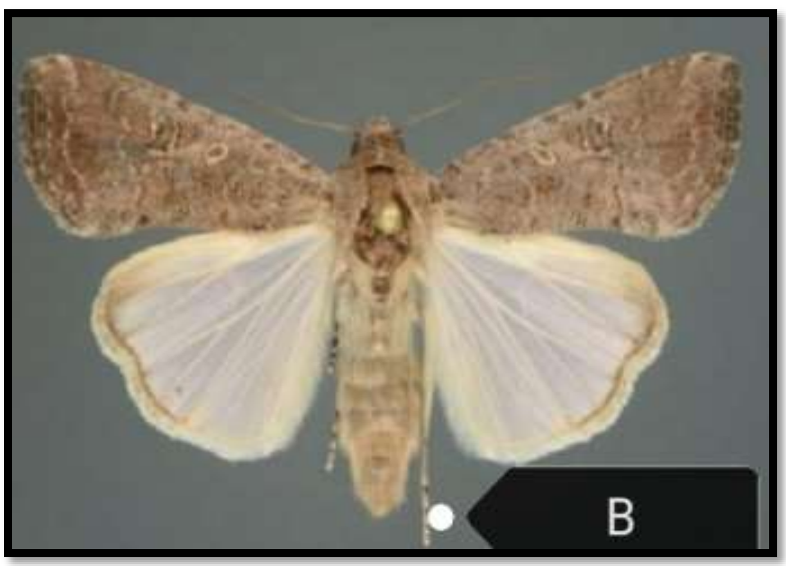


Plate No.10 Adult Moth (A Female & (B) Male

4.4 Collection and identification of the natural enemies of fall army worm at Shambat area, Khartoum State:

The results of this study showed that, more than 20 different species of predators and parasitodes were collected at Shambat Study Site in Khartoum State. These are included in (Table No.6). Some of the collection included: 3 species from order: Hymenoptera: 3 different species of Wasps, (Unkown families) (Plate No.11.), Two species from order: Hemiptera (Family: Lygaeidae, 1 species), Family: Pentatomidae. 1 species (Plate No.12), 1 species from order Coleoptera (Family: Coccinellidae (Plate No.13). Two species from order: Dermaptera (Family: Forfculidae (1 species) (Plate No.14). Also, as mentioned before, a number of larvae were found infected by different species of micro-organisms (which are shown in Plate No. 5, 6).

Table No.6 Number of Natural enemies of the fall army worm, *Spodoptera frugiperda* collected at Shambat Site

date	August				September				October				Total	Averge %
	8	**15**	**22**	**29**	**5**	**12**	**19**	26	**2**	**9**	**16**	**25**		
Coleoptera: Coccinellidae														
Coleomegillamaculate	8	7	30	7	9	13	20	15	20	10	26	10	210	17.5
Hippodamia sp	5	16	10	39	17	26	20	13	38	29	26	35	248	20.66
Cycloneda sanguinea (L.)	1	4	15	10	8	9	12	10	2	5	1	3	80	6.66
Eriopis sp	0	0	0	2	0	0	0	2	0	0	1	0	5	0.41
Carabidae ***Calosoma granulatu(sp***	0	11	17	0	12	19	10	7	9	4	9	11	120	10
Hemiptera: Lygaeidae ***Geocoris sp***	0	0	3	0	1	5	0	6	0	0	3	1	19	1.58
Pentatomidae) ***Podisus sp***	0	15	20	8	2	10	6	5	19	18	11	10	134	11.16
Dermaptera: Forfculidae) ***Doru sp***	0	0	0	0	0	1	3	0	5	1	6	6	22	1.83
Carcinophoridae) Anisolabididae ***Euborellia sp***	0	0	0	0	0	0	0	0	0	0	0	1	1	0.08
Hymenoptera:	3	10	15	6	12	25	1	26	3	10	9	13	178	14.83
Diptera: Tachinidae ***Archytas sp***	0	0	0	0		1	0	0	0	0	1	0	2	0.17
Pathogen fungi virus	0	5	0	7	0	5	0	2	0	3	10	0	22	1.9

Hymenoptera:

Plate No.11 Predator Wasps of FAW (Sourse CABI)

Hemiptera:

Zelus spp

Geocoris spp

Podisus spp

Plate No.12 Predotor Bugs of FAW

Coleoptera:

Plate No.13 Lady Bird beetle Adult&larva

Dermaptera

Plate No.14 Predator Earwig

4.5. Efficacy of an extrat of a Mixture of Pathogenic Micro-organisms on the FAW

The results of this experimenl showed good efficacy of the Pathogenic mixture on the FAW Larvae which caused 100% mortility of larvae (Table No.7). However no effect was noticed on the FAW eggs, and also on the natural enemies, which were counted and recorded. Also, no effect was noticed on the newly emerged larvae.

Table No.7 Efficacy of an extrat of a Mixture of Pathogenic Micro-organisms on the FAW with 4 weeks.

Numbers	No of plant examined weekly	1st week	2nd week	3rd week	4th week	Mortality%
Dead larvae	15	7 (2.72) a	7.3 (2.76) a	13.6 (3.76) a	15 (3.94) a	100
Natural enemies present	15	7 (2.74) a	7 (2.73) a	9.3 (3.13) ab	13.5 (3.76) a	86.7
Egg masses	15	5.6 (2.48) a	6.3 (2.60) a	7 (2.84) b	9.3(3.13)bc	62
Newely e larve	15	5.3 (2.41) a	6 (2.52) a	6 (2.78) b	7.5 (2.52) c	47
S.E. ±		1 (1.1) b	1 (1.1) b	1 (1.1) c	1 (1.1) d	6.7
LSD		(0.9)	(0.9)	(1.0)	(1.3)	(1.3)

Means followed the same letter(s) are not significantly different at $p \leq 0.05$means between brackets are transformed by($\sqrt{x+0.5}$).

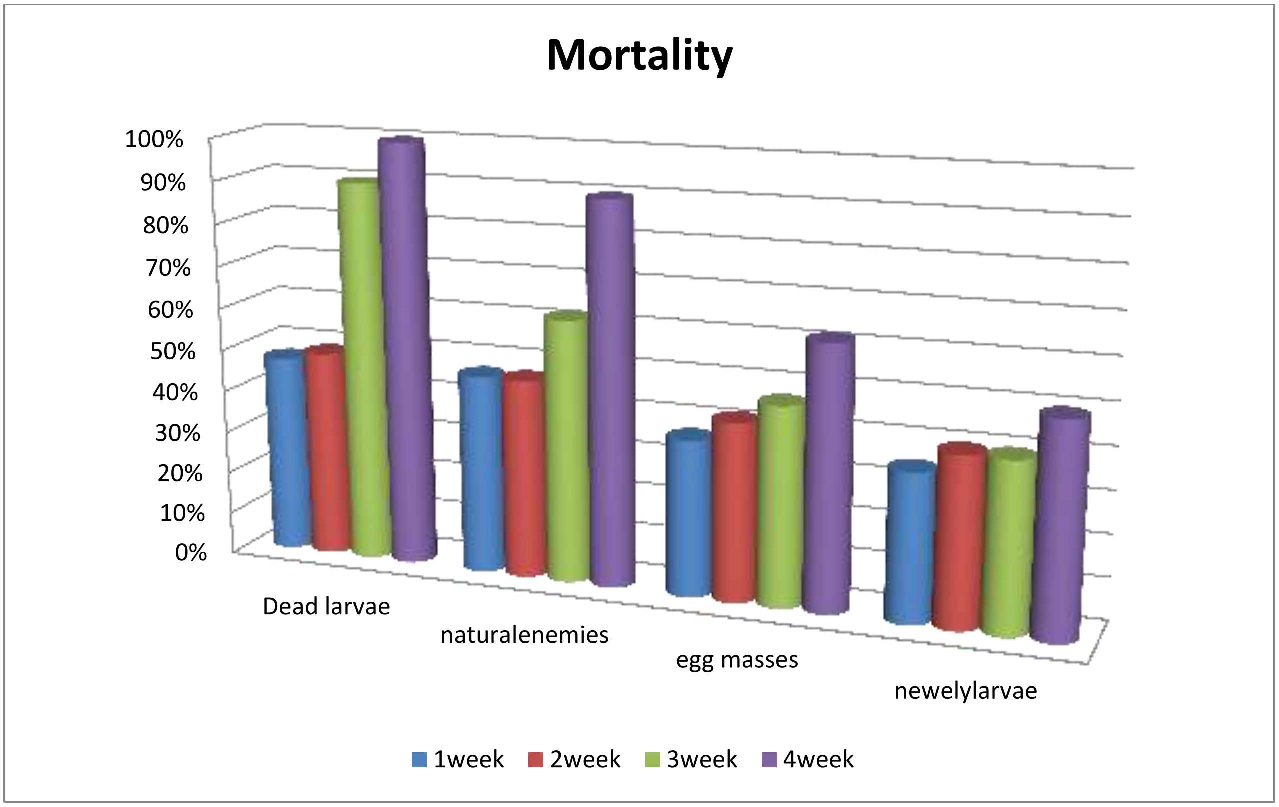


Figure No.4 Mean percentage mortality of FAW after application of an extrat of a Mixture of Pathogenic Micro-organisms on the FAW

4.6 Laboratory Trials for the Control of the Fall Army Worm *Spodoptera frugiperda* using plant extracts:

The results of these trials of the plant extracts against FAW are shown in (Tables No. 8 &11), and in (Appendices No. 4&7) The results of the Three ethanolic extracts of Neem, Black pepper and Usher showed that, all higher concentrations were effective against the FAW larvae, causing 100% mortality after 72 Hours of exposure.

4.6.1 Mortality of larvae of *Spodoptera frugiperda* of topical application of Neem seeds ethanol extract (at: 27 c^o& 50 ±10% RH)

The results of the different concentrationsare shown in Table No .8), (Figure No .5) and (Appendix No.4). These results of the ethanol extracts showed that, highest concentrations used in this study (75%) gave higher mortality percentages of (100%) after 72 hrs of exposure, compared with other concentrations. Also, it was not significantly different from the recommended dose of the standard pesticide Spinosad.

Table No. 8 Mean Mortality of NeemSeeds ethanolic extract on the larvae of *S. frugiperda*

Concentratins	No. of Larvae	After 24hs		After 48hs		After 72hs	
		No. of dead Larvae	Mortality %	No. of dead Larvae	Mortality %	No. of dead Larvae	Mortality%
10%	15	2 (1.6)	13.6 (3.8) [c]	5 (2.3)	33.3(5.8) [b]	10 (3.2)	66.6(8.2) [ab]
25%	15	4 (2.1)	26.33 (5.1) [b]	6 (2.5)	40(6.4) [b]	9 (3.1)	60(7.8) [ab]
50%	15	4 (2.1)	26.33(5.1) [b]	6 (2.5)	40(6.4) [b]	9 (3.1)	60(7.8)[a b]
75%	15	12 (3.5)	80 (9.0) [a]	14 (3.7)	93.3(9.7) [a]	15 (3.9)	100(10.02) [a]
(Standard)	15	10 (3.2)	66.6 (8.2)[a]	14 (3.7)	93.3(9.7) [a]	15 (3.9)	100(10.02)[a]
Control	15	0 (0.7)	0 (0.07) [d]	0 (0.7)	0 (0.7) [c]	0 (0.7)	0(0.07)[b]
LSD		0.8	0.8	0.9	0.9	1.3	1.3

Means followed by the same letter(s) are not significantly different at $P \leq 0.05$Means between brackets are transformed by ($\sqrt{\times} + 0.5$)

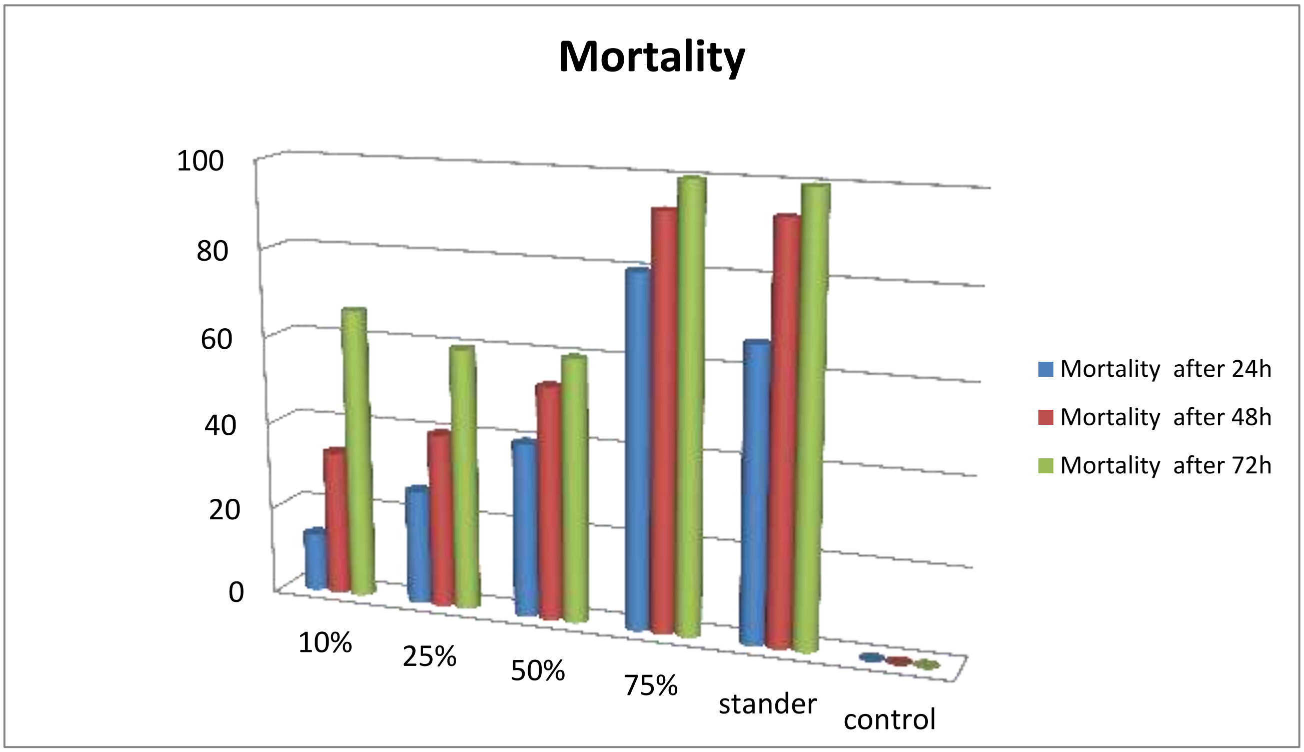


Figure No.5.Mean Mortality of larvae of *Spodoptera frugiperda*of topical application of Neem seeds ethanol extract

4.6.2 Mortality of larvae of *S. frugiperda* after topical application of black pepper seeds ethanolic extract

The results of the different concentrations are shown in (Table No.9), (Figure No.6) and in (Appendix No.5). The efficacy of the Black pepper extracts showed that, the two high concentrations (75 and 50%) also caused 100% larval mortaliy of FAW, which was comparable to that of the standard pesticide spinosad.

Table No. 9. Mean Mortality of Black Pepper Seeds ethanol extract on the larvae of *S. frugiperda*

Concentrations	No. of Larvae	After 24hs		After 48hs		After 72hs	
		No. of dead Larvae	MeanMortality%	No. of dead Larvae	MeanMortality%	No. of dead Larvae	Mortality%
10%	15	3(1.7)	20(4.5) [b]	6 (2.5)	40(6.4) [b]	15(3.9)	100(10.0) [ab]
25%	15	1(1.1)	66.6(8.2) [a]	9 (3.1)	60(7.8) [ab]	14(3.8)	93(9.7) [ab]
50%	15	5(2.3)	33.3(5.8)[b]	10(3.2)	66.6(8.2) [ab]	15(3.9)	100(10.0) [a]
75%	15	9(3.1)	20(4.5) [ab]	6 (2.5)	40(6.4) [b]	15(3.9)	100(10.0) [a]
(Standard)	15	10(3.2)	60(7.8) [a]	11(3.4)	73.3(8.6) [a]	15(3.9)	100(10.0) [a]
Control	15	0 (0.7)	0(0.07) [c]	0 (0.7)	0(0.07) [c]	0 (0.7)	0(0.07)[b]
LSD		0.7	0.7	0.9	0.9	1.2	1.2

Means followed by the same letter(s) are not significantly different at P≤ 0.0 5

Means between brackets are transformed by (√ × + 0.5)

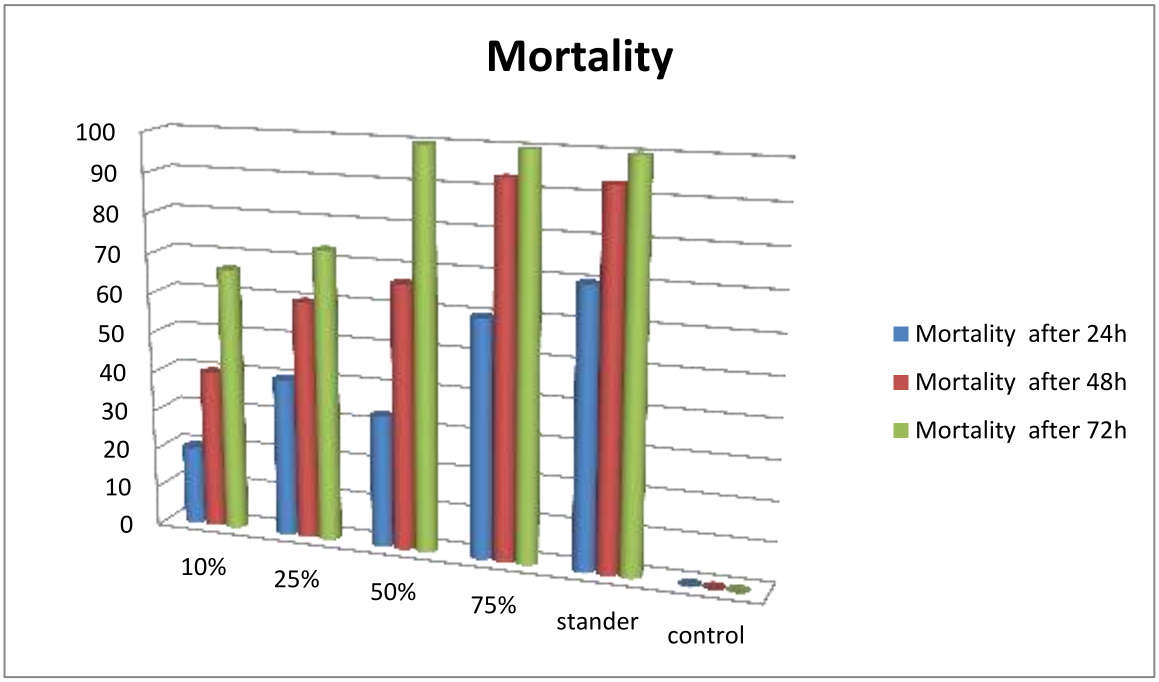


Figure No.6.Mean Mortality of larvae of *Spodoptera frugiperda*of topical application of Black Pepper Seeds ethanol extract.

4.6.3 Mortality of larvae of *S. frugiperda* after topical application of Usher leaves ethanol extract

The results of the different concentrations in (Table No.10), (Figure No.7) and (Appendix No.6), indicated that almost of concentrations caused 100% larval mortality of FAW similar to that of Spinosad.

Table No.10 .Effect of Usher leaves ethanol extract on the larvae *S. frugiperda*

Concentrations	No. of Larve	After 24hs		After 48hs		After 72hs	
		No. of dead Larvae	Mean Mortality	No. of dead Larvae	MeanMortality	No. of dead Larvae	MeanMortality
10%	15	3(1.7)	20(4.2) [c]	6 (2.5)	40(6.4)[b]	15(3.9)	100(10.0)[a]
25%	15	1(1.1)	6.66(8.2) [a]	9 (3.1)	60(7.8)[ab]	14(3.8)	100(10.0)[a]
50%	15	5(2.3)	33.3(5.8) [b]	10(3.2)	66.6(8.2)[ab]	15(3.9)	100(10.0)[a]
75%	15	7 (2.7)	64(8.0) [a]	10(3.2)	66.6(8.2)[ab]	15(3.9)	100(10.0)[a]
(Standard)	15	9(3.1)	60(7.8)[a]	11(3.4)	73.3(8.6)[a]	15(3.9)	100(10.0)[a]
Control	15	0 (0.7)	0[a](0.07)[d]	0 (0.7)	0(0.07)[c]	0 (0.7)	0(0.07)[b]
LSD		0.8	0.8.	0.9	0.9	1.3	1.3

Means followed by the same letter(s) are not significantly different at P≤0.05Means between brackets are transformed by (√ × + 0.5)

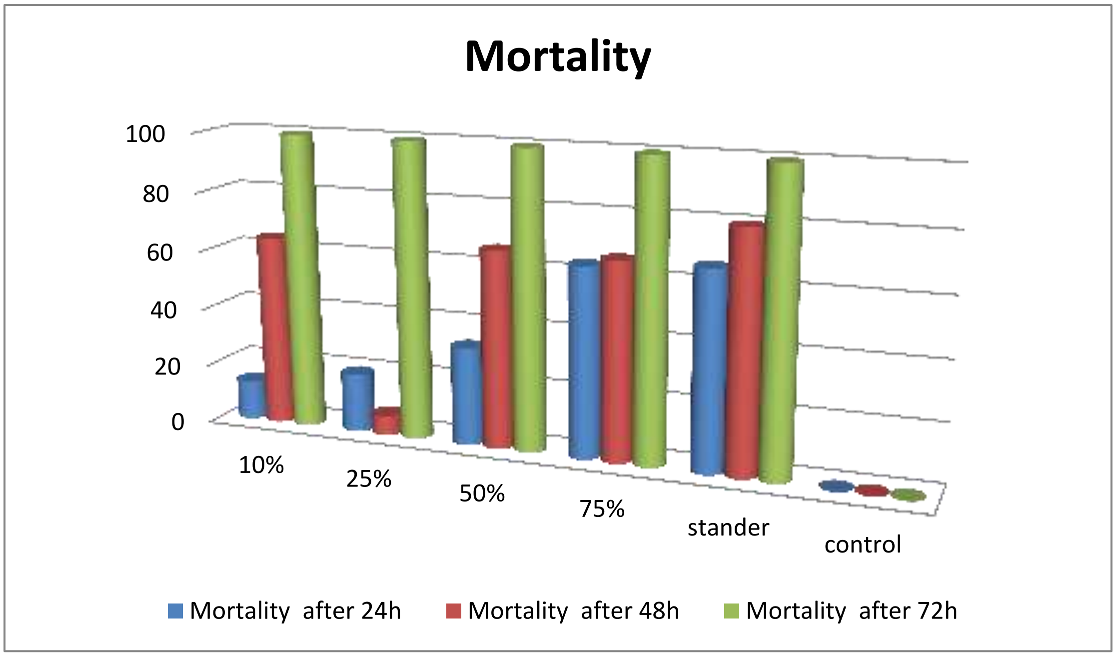


Figure No.7 Mean Mortality of larvae of *S. frugiperda* after topical application of Usher leaves ethanol extract

4.6.4 Mortality of larvae of *Spodoptera frugiperda* after topical application of Argel water extract

The results of this tests are showns in (Table NO.11), (Figure No.8) and (Appendix No.7) Very small mortality of larval mortality (6.66% -20%)were obtained .All most of the Argel Conc.pplied showed no efficacy against FAW larvae.

Table No. 11. Effect of Argel water extract on the larvae of *S. frugiperda*

Concentrations	No. of Larvae	After 24hs		After 48hrs		After 72 hrs	
		No. of dead Larvae	MeanMortality	No. of dead Larvae	Mean Mortality	No. of dead Larvae	Mortality %
10%	15	0 (0.7)	$0(0.07)^{ab}$	0 (0.7)	$0(0.07)^{a}$	1 (1.1)	$6.66(2.6)^{a}$
25%	15	0 (0.7)	$0(0.07)^{a}$	1 (1.1)	$6.7(2.6)^{a}$	2 (1.6)	$13.3(3.8)^{b}$
50%	15	1 (1.1)	$6.66(2.6)^{ab}$	1 (1.1)	$6.7(2.6)^{a}$	3 (1.7)	$20(4.5)^{ab}$
75%	15	0 (0.7)	$0(0.07)^{ab}$	0 (0.7)	$0(0.07)^{b}$	1 (1.1)	$6.66(2.6)^{d}$
(Standard)	15	10 (3.2)	$66.6(2.6)^{ab}$	13 (3.7)	$86.6(9.5)^{d}$	15 (3.9)	$100(10.0)^{c}$
Control	15	0 (0.7)	$0(0.7)^{c}$	0 (0.7)	$0(0.7)^{c}$	0 (0.7)	$0(0.7)^{a}$
LSD		0.2	0.2	0.3	0.3	0.35	0.3

Means followed by the same letter(s) are not significantly different at P≤0.05Means between brackets are transformed by (√ × + 0.5

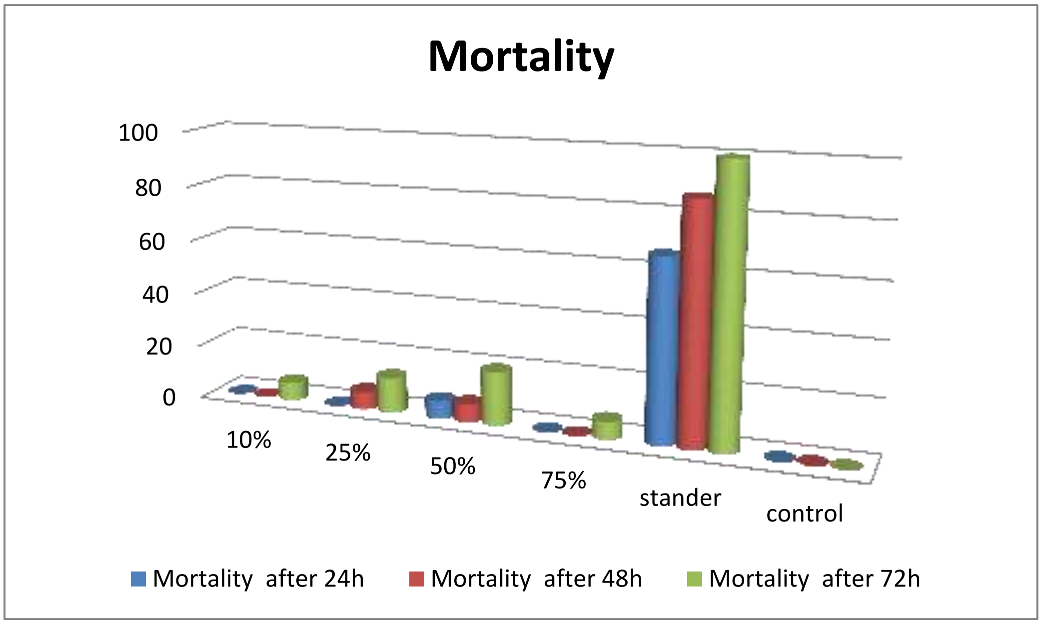


Figure No.8 Mean Mortality of larvae of *Spodoptera frugiperda*of topical application of Argel water extract

CHAPTER FIVE

5. DISCUSSION

5.1 General survey of the fall armyworm, *Spodoptera frugiperda* in Sudan:

A survey was carried out to investigate the distribution and infestation by the fall army worm (FAW), *Spodoptera frugiperda*, (J. E. Smith) in 2018, after one year of its discovery in Sudan. The survey included nine States in the country, and was made in different sites in each State. The results of the survey showed that, within less than a year (up to April, 2018), the infestation by the FAW have a wide distribution. A more detailed survey was counducted later in other States during the period Oct.2018-up to 2019, that survey confirmed the distribution of the FAW in more than half of the states in the country.The main host plants recorded were Maize, Sorghum, Tomatoes, Sunflowers, Sesame, Peanut and Millet, in addition to some vegetable crops. This tendency of wide distribution by FAW was mentioned by Johnson (1987). He stated that, migration and distribution is a major component of the life strategy of the FAW. This was noticed in USA, where FAW distribute itself over most of the Eastern Region of the USA in each growing season. Also, their long range movement from Mississippi to Canada in 30 hrs was documented. Similarly, in Asia, the FAW was first detected in India in July 2018, and within the period from January 2019, up to July 2019, the invasion of the

FAW was extended to 10 other Asian countries (Relief Web, 2019).The fast invasion and distribution of the FAW in Sudan, as reported in the present study, and in other countries, requires coordinated actions between the farmers, in the affected and risk areas, and the national governments at one side, and between national governments and regional or international institutions at the other side, to combat this serious transpoundery pest. Concerning the situation in Sudan, the farmers should apply regular monitoring in their fields (for example, by using pheromone traps, or visually), and report information of new invasive pests immediately to the Plant Protection Authorities in their Regions. On the other side, the government should promote awareness of FAW, its identification, damage and control measues, and in particular IPM, to the farmers. In addition, the government should ensure that, consistent advice on new control approaches is disseminated through multiple channels and advisory services, for the farmers.

5.2. Studies on the percentage of damage of the fall armyworm, in five site in Khartoum State:

Although in trials symptoms of damage of FAW and those of stembores are similar, thresholds and control measures differ. Therefore, it is important to find the live larvae and determine which insect is causing the damage. Goergen *et al*., (2016) mentioned that, farmers were able to recognize the fall armyworm, and the majority of them observed larvae attacking all maize crop growth stages; specially early growth stages (vegetative stage). Similarly, Abrahams *et al*., (2017) and Capinera (2017) also found that, fall army worm late-instar larvae damage the growing points of the plants causing defoliation and dead hearts. In the present study, the results obtained revealed that there is a significant difference between mean percentage of damage of FAW from the five areas during October, November and December. The Mean percentage of damage in November and December was significantly higher than October. The Mean percentage of damage in Shambat, Touti and Al Shehainab was significantly higher than Kafouri and Alfakihashim. This may be attributed to variation in maize sowing time and cultural practices in different locations. The present results are in line with Jubara (2018) (personal communication).

5.3. Studies on the biology of the fall army worm *Spodoptera frugiperda*

In the present study, the biological parameters observed and recorded during the development of the FAW from oviposition up to the adult emergence, within a period of Twelve Months, are shown in Table 4.

During the past decades, large numbers of studies were made on the biology of the FAW in various countries in the world (for example, Pitre and Hogg, 1983; Capinera, 2017; Silva *et al*., 2017; Igyuve *et al*., 2018; Sharanabasappa *et al*.,2018 and Lamsal *et al*., 2020).

By reviewing those studies it was found that, in comparison, the results shown in the present study were in full agreements with most of the results recorded in those studies. For example, the pre-oviposition period is similar to those reported by Pitre and Hogg (1983) and Sharanabasappa *et al*. (2018). Also, the oviposition period shown (2-3 days) is in agreement with those recorded by Silva *et al*. (2017) and Lamsal *et al*. (2020). In addition, six larval instars were recorded in the present study, which were similar to those reported in some of the above mentioned studies (e.g., Pitre and Hogg, 1983; Sharanabasappa *et al*., 2018 and Lamsal *et al*., 2020).

The regular observations of the (FAW) made in the present study in the fields, and in the laboratory, showed that its reproduction continued during the whole year round. Under normal laboratory conditions, Six generations of the (FAW) were recorded during its development within Twelve Months. These are shown in Table 5. According to the observations made, these generations of the FAW can be classified on seasonal bases to the following: Two generations (the First and the Second generations) in the autumn, from September to late November. The third generation in the winter, from December to late March. The fourth and the fifth generations in the summer (from April to late June) and the sixth generation in autumn (during July and August). Considering the number of FAW generations per year, the results of the present study are in agreement with those reported by Abraham, *et. al.*, (2017). They mentioned that, in Florida the (FAW) breeds continually, and the life cycle takes one month in summer, two months in spring and autumn and Three months in winter. On the other hand, Tendeng *et, al*., (2019), in senegal, recorded Fifteen generations per year. However, Capinera (2017) mentioned that, the number of annual generations of the (FAW) differs according to the different areas and different seasons.

5.4. Collection, Identification, the natural enemies of fall army worm in Khartoum State

In the present study, collection and identification of natural enemies at Shambat study site showed that, there are a number of predators and parasites of FAW that are available in the fields (Table 6). In addition, at Al Shehainab study site in Omdurman, large numbers of larvae were found infected by some pathogenic micro-organisms.

Collection and Identification of FAW natural enemies were also made in other countries. Molina-Ochoa *et al.*, (2003) recorded more than 30 different species of parasites and parasitoids of FAW from Orders: Diptera and Hymenopera. Koffi *et al.*, (2020) reported about 10 species of parasites and predators of FAW in Ghana. Also, Abang et *al.*, (2021) mentioned that, 7 species of natural enemies of FAW were abundant and recoded from different ecological areas in Cameroon.

5.5 Efficacy of an extract a Mixture of Pathogenic Micro-organisms on the FAW

The results of this preliminary study of the Application of a solution of an extract of a mixure of Pathogenic micro-organisms showed good efficacy against FAW larvae under field condition (Table No.7). Anumber of naturally accuring pathogens (eg Virus, Bactria, and Fungi) have been shown to affect FAW larvae in the fields (FAO, 2018). Also, previons experiene in the Americas indicated that small holder farmers used to recyde the pathogenic larvae of FAW by collecting and spraying them back on maize for field for FAW control (FAO, 2018).

5.6. Laboratory Trials for the control of the fall army worm *Spodoptera frugiperda*, using plant extracts

The extensive studies carried out during the last decades proved the potential of plant extracts as alternative insect pest control agents (Pavela , 2016; Khan *et al*., 2017). Concerning the FAW, Rioba and Stevenson (2019) in their review stated that, 69 plant species were found as effective control agents against FAW in various parts of the world. Likewise, in the present study, the bioassay tests showed that, the Three Phenolic extracts of Neem, Usher and Black pepper caused mean percentage mortality between 66.6 – 93% of the FAW larvae after 48 hours. Also, a 100% larval mortality was obtained with each one after 72 hour, which was comparable to that of the standard insecticide.

The results of the present study are almost in full agreement with those of Sisay *et al*., (2019), who stated that, Three Botanical extracts (including Neem) showed equal efficacy with that of Four Synthetic insecticides against larvae of FAW after 72 hours. Also, efficacy of the Black Pepper extracts, shown in (Table 2) is comparable to that of Cellis *et al*., (2020) who mentioned that, methanolic extracts of Six Piper species caused larval mortality of FAW similar to that obtained by the insecticide Chlorpyrephos. In addition, efficacy of Usher extracts shown in the present study is similar to that of Santos (2012) (cited by Rioba and Stevenson, 2019) who showed that, morality of FAW larvae increased by feeding on maize leaves impregnated by Usher leaves extracts.

The present study is the first one that indicates the effectiveness of three botanical extracts against FAW in Sudan. Furthermore, the highest concentration of each extract showed high efficacy against the FAW larvae, which was comparable to that of the standard insecticide Spinosad after 72 hours. The strong insecticidal activity of Spinosad against many insect pests, particularly of Lepidoptera, was reported in previous studies (Salgado, 1998; Huang and Subramanyan, 2007).

Based on the results of the above mentioned studies, and the present results, which showed the equal efficacy of the botanical extracts and the Standard insecticide Spinosad, it is worth considering the costs of the FAW control by each group, and the impact on the Environment. The price of "100 ml of Spinosad" in the Pesticide Market in Khartoum State equal 750 SDG, and in the Local Market, "One Pound of Black pepper "equal 5oo SDG. In comparison, Tens of Kgs of Neem seeds, or of Usher leaves, can be collected "free of charge "at any time from the open fields in Khartoum State.

CONCLUSION AND RECOMMENDATIONS

1-Survey, Biology and Ecology of FAW in Sudan

The regular surveys and observations made on the Biology and Ecology of FAW in the present study indicated that: it is a serious pest, its breeding is continuous through the year round and so it represents a menace for the different crops in the field.

Accordingly, this study recommended that:

a. All measures for detection and identification of the pest should be made early in each season in order to compat this serious transpoundry pest.

b. More studies on the biology and ecology of FAW would be of prime importance to determine a suitable time for its effective management in future.

2. Natural Enemies of FAW

Collection and identification of natural enemies of FAW should be made in different states in the country, in order to form a data base for effective natural enemies to be applied in an IPM programs against FAW.

3. Application of Plant Exracts for FAW Management:

The present study proved the efficacy of extracts of three plants (Neem, Black pepper and Usher) against larvae of FAW. Furthermore, the study showed that, the plant extracts are more economic and environmentally safe compared to synthetic pesticides.

Accordingly, this study recommended that:

More studies should be applied to explore the potentiality of other indigenous plants which can save the hard currency and reduce environmental hazards.

Application of an extract of a mixure of Pahogens for FAW control :

The results of this preliminary study of the application of a solution of a mixure of Pahogenic micro-organisms showed good efficacy against FAW larvae under field condition.

Further suggested studies:

A life table study should be made for more understanding of   the faw   annual generations.

More studies should be made to identify new natural enemies, and also to explore the potential of other plant extract for faw.

Future studies should be made to explore the potential of pathogenic micro organisms as biocontrol agents for faw.

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Appendices

1. the Mean percentage of fall army worm, *Spodoptera frugiperda* five Sites October, 2018

		the mean percentage Natural damage in five station%			
Site	N.O.plant	1st week	2nd week	3rd week	4th week
Touty	50	32(5.6)	56(7.5)	52(7.3)	50(7.1)
Shembat	50	6(2.52)	64(6.1)	42(6.6)	52(7.3)
ElfakyHashim	50	6(2.52)	30(5.5)	40(6.4)	36(5.9)
Kafoury	50	10(3.24)	38(9.1)	38(9.1)	38(6.2)
Alshehinab	50	32(5.6)	56(7.5)	42(6.6)	38(6.2)

2. The Mean percentage Natural damage of the fall army worm, *Spodoptera frugiperda* in five Sites in November 2018

		the percentage Natural damage in five station100%			
Site	NO.plant	1st week	2nd week	3rd week	4th week
Shembat	50	64(6.1)	40(6.4)	24(2.37)	100(10.02)
Alfaki hasheim	50	68(5.9)	84 (6.5)	38(6.2)	38(6.2)
Kafouri	50	30(5.5)	38(6.2)	38(6.2)	52(7.3)
AlShihnab	50	68(5.9)	84 (6.5)	100(10.02)	35(5.8)
Touti	50	64(6.1)	40(6.4)	63(5.9)	74(8.6)

3.The Mean percentage Natural damage of the fall army worm, *Spodoptera frugiperda* in five Sites in December 2018

		the percentage Natural damage in five station			
Site	NO.plant\	1st week	2nd week	3rd week	4th week
Shembat	50	64(8.1)	46(6.9)	26(4.7)	100(10.02)
Kafoury	50	30(5.5)	38(6.2)	38(6.2)	100(10.02)
AlShihnab	50	70(8.4)	84(6.5)	100(10.02)	70(8.2)
Alfaki hasheim	50	64(8.1)	46(6.9)	70(8.4)	36(5.9)
Touti	50	64(6.1)	40(6.4)	63(5.9)	100(10.02)

4. Mean mortality of larvae of *Spodoptera frugiperda* of topical application of Neem seeds ethanol extract at 24hs

Title: topical

Function: ANOVA-1

A N A L Y S I S O F V A R I A N C E T A B L E

24hs treatment /statistics descriptive

/missing analysis

F.Test P.value

16.80 0.00

1	Number	SD	mean
1	3.00	2.00	12.00
2	3.00	3.61	6.00
3	3.00	1.00	4.00
4	3.00	2.00	2.00
5	3.00	1.00	10.00
6	3.00	0.00	0.00
Total	18.00	9 .61	23. 0

A N A L Y S I S O F V A R I A N C E T A B L E

24 h.s by treatment /statistics descriptive

/missing analysis

F.Test	P.value
16.80	0.00

1	Number	SD	mean
1	3.00	2.00	12.00
2	3.00	3.61	6.00
3	3.00	1.00	4.00
4	3.00	2.00	2.00

5	3.00	1.00	10.00
6	3.00	0.00	0.00
Total	18.00	9 .61	23. 0

5.Mean mortality of larvae of *Spodoptera frugiperda* of topical application of Neem seeds ethanol extract at 48hs

A N A L Y S I S O F V A R I A N C E T A B L E

48 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
14.84	0.00

1	Number	means	S.D
1	3.00	14.00	1.00
2	3.00	8.00	2.65
3	3.00	6.00	1.73
4	3.00	5.00	5.00
5	3.00	14.00	1.00
6	3.00	0.00	0.00
Total	18.00	3 7 .00	9. 3 8

Mean mortality of larvae of *Spodoptera frugiperda*of topical application of Neem seeds ethanol extract at 72hs

A N A L Y S I S O F V A R I A N C E T A B L E

72 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
11.59	0.00

1	Number	mean	S.D
1	3.00	14.00	1.00
2	3.00	8.00	2.65
3	3.00	8.00	2.46
4	3.00	10.00	5.00
5	3.00	15.00	0.00
6	3.00	0.00	0.00
Total	18.00	55 .00	22. 22

6. Mean Mortality of larvae of *Spodoptera frugiperda*of topical application of black pepper seeds ethanol extract (at: 27 cº& 50 ±10% RH) after 24hs

A N A L Y S I S O F V A R I A N C E T A B L E

24 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
8.76	0.001

1	Number	mean	S.D
1	3.00	7.00	4.36
2	3.00	5.00	1.00
3	3.00	1.00	1.00
4	3.00	3.00	1.00
5	3.00	9.00	1.73
6	3.00	0.00	0.00
Total	18.00	25 .00	9. 09

.MeanMortality of larvae of *Spodoptera frugiperda* of topical application of black pepper seeds ethanol extract (at: 27 cº& 50 ±10% RH) after 48hs

A N A L Y S I S O F V A R I A N C E T A B L E

24 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
17.93	0.00

1	Number	mean	S.D
1	3.00	11.67	2.89
2	3.00	10.67	2.08
3	3.00	9.33	2.52
4	3.00	6.00	1.00
5	3.00	11.33	0.58
6	3.00	0.00	0.00
Total	18.00	49 .00	9. 07

7.MeanMortality of larvae of *Spodoptera frugiperda* of topical application of black pepper seeds ethanol extract (at: 27 c^{o}& 50 ±10% RH) after 72hs

A N A L Y S I S   O F   V A R I A N C E   T A B L E

24 hs by treatment /statistics descriptive

/missing analysis

F.Test P.value

5.16 0.009

1	Number	mean	S.D
1	3.00	10.00	5.00
2	3.00	4.00	5.29
3	3.00	3.00	1.00
4	3.00	2.00	2.65
5	3.00	10.00	1.00
6	3.00	0.00	0.00
Total	18.00	28.00	14

7. MeanMortality of larvae of *Spodoptera frugiperda* of topical application of Usher leavesethanol extract (at: 27 c°& 50 ±10% RH)after24hs

A N A L Y S I S O F V A R I A N C E T A B L E

24 hs by treatment /statistics descriptive

/missing analysis

F.Test P.value

37.26 0.00

1	Number	mean	S.D
1	3.00	10.00	0.00
2	3.00	12.00	1.00
3	3.00	7.00	1.00
4	3.00	12.00	2.65
5	3.00	8.50	1.00
6	3.00	0.00	0.00
Total	18.00	49.50	5.6

8.Mean mortality of larvae of *Spodopterafrugiperda*of topical application of Usher leavesethanol extract (at: 27 c°& 50 ±10% RH) after 24hs

A N A L Y S I S O F V A R I A N C E T A B L E

48 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
-	-

1	Number	mean	S.D
1	3.00	15.00	0.00
2	3.00	15.00	0.00
3	3.00	15.00	0.00
4	3.00	15.00	0.00
5	3.00	15.50	0.00
6	3.00	0.00	0.00
Total	18.00	75.00	0.00

9.Mean mortality of larvae of *Spodopterafrugiperda*of topical application of Usher leavesethanol extract (at: 27 cº& 50 ±10% RH) after 24hs

A N A L Y S I S O F V A R I A N C E T A B L E

72 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
-	-

1	Number	mean	S.D
1	3.00	15.00	0.00

2	3.00	15.00	0.00
3	3.00	15.00	0.00
4	3.00	15.00	0.00
5	3.00	15.50	0.00
6	3.00	0.00	0.00
Total	18.00	75.00	0.00

Appendix7. MeanMortality of larvae of *Spodoptera frugiperda* of topical application of hargel water extract (at: 27 cº& 50 ±10% RH) after 24hs

A N A L Y S I S O F V A R I A N C E T A B L E

24 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
11.64	0.00

1	Number	means	S.D
1	3.00	0.00	0.00
2	3.00	1.00	0.00
3	3.00	0.00	0.00
4	3.00	0.00	0.00
5	3.00	10.00	5.00

6	3.00	0.00	0.00
Total	18.00	11.00	5.00

10. Mean mortality of larvae of *Spodoptera frugiperda* of topical application of hargel water extract (at: 27 cº& 50 ±10% RH) after48h

A N A L Y S I S O F V A R I A N C E T A B L E

48 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
11.64	0.00

1	Number	mean	S.D
1	3.00	0.00	0.00
2	3.00	1.00	0.00
3	3.00	0.00	0.00
4	3.00	0.00	0.00
5	3.00	10.00	5.00
6	3.00	0.00	0.00
Total	18.00	11.00	5.00

11.Mean mortality of larvae of *Spodoptera frugiperda of* topical application of hargel water extract (at: 27 cº& 50 ±10% RH) after72hs

A N A L Y S I S O F V A R I A N C E T A B L E

72 hs by treatment /statistics descriptive

/missing analysis

F.Test	P.value
16.80	0.00

1	Number	means	S.D
1	3.00	6.00	2.00
2	3.00	6.00	3.61
3	3.00	4.00	1.00
4	3.00	2.00	2.00
5	3.00	10.00	1.00
6	3.00	0.00	0.00
Total	18.00	19.00	9.6

12.Mean mortality of larvae of *Spodoptera frugiperda* of topical application of Neem seeds ethanol extract at 24hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R	R	
10%	15	0	4	2	12
25%	15	3	5	4	6
50%	15	5	10	3	4
75%	15	10	12	14	2
Stander	15	10	11	9	10
Control	15	0	0	0	0

13.Mean mortality of larvae of *Spodoptera frugiperda*of topical application of Neem seeds ethanol extract at 48hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	0	10	5	5
25%	15	7	4	7	6
50%	15	10	9	5	8
75%	15	14	13	15	14
Stander	15	13	15	14	14
Control	15	0	0	0	0

Mean Mortality of larvae of *Spodoptera frugiperda* of topical application of Neem seeds ethanol extract at72hs

Concentrations	Number oflarvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	4	10	15	10
25%	15	14	13	10	9
50%	15	10	9	5	8
75%	15	5	10	15	14
Stander	15	15	15	15	15
Control	15	0	0	0	0

14.Mean mortality of larvae of *Spodoptera frugiperda* of topical application of black pepper seeds ethanol extract (at: 27 c^o& 50 ±10% RH) after 24hs

Concentrations	Number oflarvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	2	4	3	3
25%	15	0	1	2	1
50%	15	6	4	5	5
75%	15	2	9	10	7
Stander	15	10	7	10	9
Control	15	0	0	0	0

15.Mean mortality of larvae of *Spodoptera frugiperda* of topical application of Black pepper seeds ethanol extract (at: 27 cº& 50 ±10% RH)after48hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	3	5	1	2
25%	15	3	4	2	3
50%	15	0	10	2	4
75%	15	10	15	5	10
Stander	15	10	9	11	10
Control	15	0	0	0	0

16.Mean mortality of larvae of *Spodoptera frugiperda* of topical application of Black pepper seeds ethanol extract (at: 27 cº& 50 ±10% RH)after72hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	0	5	1	2
25%	15	3	4	2	4
50%	15	0	10	2	3
75%	15	10	15	5	10
Stander	15	10	9	11	10
Control	15	0	0	0	0

17. Mean mortality of larvae of *Spodoptera frugiperda*of topical application of Usher leavesethanol extract (at: 27 cº& 50 ±10% RH) after 24hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	5	6	10	7
25%	15	9	11	10	12
50%	15	12	11	13	7
75%	15	10	10	10	10
Stander	15	13	11	12	10
Control	15	0	0	0	0

18. Mean mortality of larvae of *Spodopterafrugiperda*of topical application of Usher leaves ethanol extract (at: 27 cº& 50 ±10% RH)after48hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	15	15	15	15
25%	15	15	15	15	15
50%	15	15	15	15	15
10%	15	15	15	15	15
Stander	15	15	15	15	15
Control	15	0	0	0	0

Mean Mortality of larvae of *Spodoptera frugiperda*of topical application of Usher leaves ethanol extract (at: 27 cº& 50 ±10% RH) after72hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	15	15	15	15
25%	15	15	15	15	15
50%	15	15	15	15	15
75%	15	15	15	15	15
Stander	15	15	15	15	15
Control	15	0	0	0	0

19. Mean mortality of larvae of *Spodoptera frugiperda* of topical application of hargel water extract (at: 27 cº& 50 ±10% RH) after24hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	0	0	0	0
25%	15	0	0	0	0
50%	15	1	1	1	1
75%	15	0	0	0	0
Stander	15	10	15	5	10
Control	15	0	0	0	0

Mean.Mortality of larvae of *Spodoptera frugiperda*of topical application of hargel water extract (at: 27 cº& 50 ±10% RH) after48hs.

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	0	0	0	0
25%	15	1	1	1	1
50%	15	0	0	3	1
75%	15	2	3	1	2
Stander	15	11	12	15	13
Control	15	0	0	0	0

20. Mean mortality of larvae of *Spodoptera frugiperda* of topical application of hargel water extract (at: 27 cº& 50 ±10% RH) after 72hs

Concentrations	Number of larvae	Mortality of larvae			Mean
		R1	R2	R3	
10%	15	0	4	14	2
25%	15	3	5	4	4
50%	15	5	10	3	6
75%	15	10	12	2	2
Stander	15	10	11	9	10
Control	15	0	0	0	0

21. Life Cycle on fall armyworm