SURVEY AND MANAGEMENT OF SESAME WEBWORM *Antigastra catalaunalis* DUPONCHEL (LEPIDOPTERA: PYRAUSITIDAE) IN NORTH GONDAR ADMINISTRATIVE ZONE

MSc THESIS

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SURVEY AND MANAGEMENT OF SESAME WEBWORM *Antigastra catalaunalis* DUPONCHEL (LEPIDOPTERA: PYRAUSITIDAE) IN NORTH GONDAR ADMINISTRATIVE ZONE

By

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Major Advisor: Samuel Sahile (PhD)

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POSTGRADUATE DIRECTORATE

As dissertation research advisory committee member (ACM), I hereby certify that I have read and evaluated this dissertation prepared under our guidance by **Yohannes Ebabuye Andargie** entitled **SURVEY AND MANAGEMENT OF SESAME WEBWORM *Antigastra catalaunalis* DUPONCHEL (LEPIDOPTERA: PYRAUSITIDAE) IN NORTH GONDAR ADMINISTRATIVE ZONE.** I recommend that it be submitted as fulfilling the dissertation requirement.

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DEDICATION

This paper is dedicated to my late mother **Wosenyelesh Bogale**

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bona fide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at University of Gondar and is deposited at the University Library to be made available to borrowers under rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Place: University of Gondar, Gondar

Date of Submission: -----------------------

BIOGRAPHICAL SKETCH

The author, Yohannes Ebabuye was born on July 9, 1985 in Gondar town, in North Gondar zone. He completed his primary education at Atse Fasil School and secondary education at Azezo Senior Secondary School.

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ABBREVIATIONS AND ACRONYMS

ANOVA – Analysis of Variance

CSA – Central Statistics Agency

CV – Coefficient of Variation

CIMMYT - Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center)

cm – centimeter

EC – Emulsifiable Concentrate

ECX – Ethiopian Commodity Exchange

GARC – Gondar Agricultural Research Center

GENMOD – SAS statistical analyzing software procedure that works logistic regression function

GPS – Geographical Positioning System

ha – Hectare

IGR- Insect Growth Regulators

IPGRI – International Plant Genetic Resources Institute

L – Liter

LRT – Likelihood Ratio Test

LSD – Least Significant Difference

mm – Millimeter

MRR – Marginal Rate of Return

NCP – Number of Capsules per Plant

NBPGR – National Bureau of Plant Genetic Resources

PH – Power of Hydrogen

RCB – Randomized Complete Block

SAS-GLM – Statistical Analysis Software-General Linear Model

SBN-SP – Sesame Business Network-Support Program

SNNPR – Southern Nations Nationalities and peoples Region

SPSS – Statistical Package for Social Science

SC – Suspension Concentrate

TSW – Thousand Seed Weight

V/V – Volume by Volume

WOARD – Woreda Office of Agriculture and Rural Development

WPP – Webbed Plants Percentage

W/V – Weight by Volume

SAS CORR – SAS statistical analyzing software procedure that works correlation function

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BY

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ABSTRACT

Sesame (Sesamum indicum L.) is an important oil crop in Ethiopia. Despite its importance and growth in production, area coverage and market value, a wide range of pests such as sesame web worm, sesame seed bug, bacterial blight and phyllody attack sesame. Among these, the webworm, (Antigastra. catalaunalis) is the most important one in Ethiopia. It attacks the crop in all growth stages. Repeated occurrence and damage of this pest has forced farmers to use insecticides that have negative effect on human, environment and market. To ameliorate these consequences, non chemical options or chemicals with the least hazard should be used. Therefore, the present work was aimed to assess the importance of sesame webworm, evaluate some control measures and recommend management option. Ninety fields were surveyed making a stop at every 3-5 km intervals in Metema, Tach Armachiho, Tegedie and Mierab Armachiho woredas. A field experiment with 10 treatments; two planting dates (planting at the onset of rain fall and the second 10 days later) and insecticide sprays (Neem kernel aqueous extract, Jatropha seed aqueous extract, Malathion 50% EC, Lamda-cyhaolathrin 5% EC, and a none sprayed control) were arranged in a factorial RCBD with three replications. Results revealed that improved varieties, elevations greater than 700 masl, early June planting, high population density, weed density >40/m^2 were highly associated with sesame webworm incidence. Planting at the onset of rainfall had significantly lower (P<0.05) damaged capsules per plant and gives significantly higher (P<0.01) number of capsules per plant, plant height, TSW and yield. The interaction revealed early planting with neem aqueous spray resulted in significantly lower (P<0.01) percent of webbed plants whereas late plating with no spray application resulted in greater percent of webbed plants. Planting on the onset of rainfall with Malathion spray resulted in high MRR while spraying neem and other sprays resulted in negative MRR. Therefore, planting on the onset of rainfall with Malathion spray can be recommended to reduce sesame webworm infestation.

Key words: *A. catalaunalis*, webworm, sesame, neem, aqueous extract, spray

1. INTRODUCTION

Sesame (*Sesamum indicum* Linn.) from a member of the order tubiflera and family Pedaliaceae, is an old and important lowland oilseed crop being cultivated in tropics, subtropical region of India and other parts of the world (Karuppaiah and Nadarajan, 2013). The Latin binomial *Sesamum indicum* L. has a synonym, *S. orientale* L. (IPGRI and NBPGR, 2004) and it is an erect herbaceous annual plant that has two growth characteristics: indeterminate and determinate, with heights of up to two meters. Most varieties show an indeterminate growth habit, which is also shown as a continuous production of new leaves, flowers and capsules as long as the environment remains suitable for growth (Carlsson *et al.*, 2008). Sesame seed are small and ovate with two distinct types, cream-coloured and black (Ali and Jan, 2014). It is grown in areas with annual rainfall of 625-1100mm and temperature of >27^{0}C and well adapted to a wide range of soils, but requires deep, well-drained, fertile sandy loams (Geremew *et al.*, 2012).

It is an important source of edible oil and is widely used as one of the ingredients in food products especially in bakery foods and animal feed (Ali *et al*., 2007). It is also used in confectioneries, cookies, cake, margarine and bread making and the oil is used in the manufacture of soaps, cosmetics, perfumes, insecticides and pharmaceutical products (Karuppaiah and Nadarajan, 2013). Sesame oil has medicinal and pharmaceutical value and is being used in many health care products (Ali *et al*., 2007).

It is becoming the most important oil crop for Ethiopia’s export earnings and for increasing the potential of generating income for the local population (Gelalcha, 2009). The oil seeds sector is one of Ethiopia’s fastest-growing and important sectors, both in terms of its foreign exchange earnings and as a main source of income for over three million Ethiopians (Gelalcha, 2009). It is the second largest source of foreign exchange earner after coffee. Study reports indicate that Ethiopia is among the top-five producers of sesame seed, linseed and Niger seed (Wijnands *et al.*, 2009).The major sesame seed production regions are situated in the North West and South West Ethiopia (CSA, 2011). The potential for further growth, both in terms of quantity and quality, through improved production techniques and productivity factors is considered to be great.

In the last few years, sesame production and marketing has shown significant growth. According to Gelalcha, (2009), the total area under sesame production was about 64,000 ha in 1997 and in nearly ten years' time the total area of sesame production has increased by more than 200% to about 211,000 ha. Similarly, the area coverage of the same crop during the same years was increased from 211,312 hectares in 2006/7 (CSA, 2007) to nearly 384,683 hectares in 2010/11 (CSA, 2011) indicating an increment of area coverage at about 45%. According to (CSA, 2011) report, in 2009/2010 and of 'Meher' season of sesame production, area has shown 21.8% increment i.e. from 315,843ha to 384,683ha respectively. The production area of sesame in 2014/2015 'meher' sesason has also showed an increment and it was 420,494 ha (CSA, 2015). The largest sesame production areas are situated in North West and South West Ethiopia where North Gondar Administrative zone has the largest area coverage 129,813.34 hectares (CSA, 2015). This shows increased sesame production was mainly dependent on extensive farming than intensive. This indicates that the use of improved technologies would ultimately result to achieve maximum yield from this large area size. Thus, it appears that the current increment of sesame area coverage and production is highly influenced by an increasing market value in international market for Ethiopian sesame seed (Zerihun, 2012). Besides its growth in production area and increasing market value, a wide range of weed species, insect pests, and diseases attack sesame around the world. In Ethiopia, weeds presume primary importance, followed by insect pests and diseases. Among insects; sesame webworm *(Antigastra catalaunalis)*, sesame seed bug (*Elasmolomus sordidus*), gallmidge (*Asphondilia sesami*), green vegetable bug *(Nezara viridula)* grasshoppers, African Bollworm, (*Helicoverpa armiger*), and crickets have been and hey become more serious as crop acreage expands and mono-cropping is practiced largely (Selemun, 2011; Geremew *et al.,* 2012).

Sesame is attacked by different insect pests during its different growing stages, but sesame webworm, (*A. catalaunalis*) is the most important pest since it was reported to attack the crop in all growth stage starting from two weeks after emergence (Suliman *et al.,* 2013b) and causes 25%-35% yield loss (Geremew *et al*., 2012).

In North Gondar sesame farms webworm is becoming the major production constraint. The repeated occurrence of the insect pest made farmers look for control options and forced them to spray insecticides, usually Malathion 50% EC. The intensive use of insecticides is known to have lots of consequences for human, living environment and market. In order to get rid of such consequences, non chemical options must be searched for the control of this pest and if chemicals are to be used, the least hazardous ones should be chosen which is ultimately crucial for the sustainability of the increasing sesame production. This is due to the reason that synthetic insecticides are proved to have adverse effects, which could be clearly shown in the resurgence of pests, injury to beneficial insects, development of resistance, environmental pollution, high cost of application and increasing price of the chemicals (Suliman *et al.*, 2013a). So, alternative insecticides of plant origin with less toxicity and minimum damage to the environment must be obtained. No matter how there is little information available on the integrated use of different approaches for managing sesame webworm on sesame in Ethiopia, a lot is needed to be explained in North Gondar sesame production areas on the importance of sesame webworm and control methods as this area is one of the major sesame production corners in the country. Therefore, the present work attempts to address the following objectives.

2. OBJECTIVES

2.1. General Objective

- To assess distribution and damage extent and evaluation of some selected management options of sesame webworm, *Antigastra catalaunalis.*

2.2.Specific objectives

- To assess distribution and damage extent of sesame webworm, *Antigastra catalaunalis* in major sesame growing areas of the North Gondar administrative zone
- To evaluate some of the selected sesame webworm, *Antigastra catalaunalis* management options.

3. LITERATURE REVIEW

3.1. Sesame

3.1.1. Taxonomy, morphology and ecology

Sesame [*Sesamum indicum* (L.)], belongs to order tubiflera and family Pedaliaceae which contains 60 species organised into 16 genera (Nafe, *et al., 2010;* Ashri, 1998). It is known by common names beni, benne and beni seed (Sheahan, 2014). It is an annual self-pollinating plant with an erect, pubescent, branching stems (Morris, 2002). Sesame crop contain 13 pair of the chromosome (Chromosome No. 2N = 26) (Nafe, *et al., 2010*). It is a broadleaved plant that grows about 155 to 185 cm tall, with height dependent on the variety and growing conditions. Large, white, bell-shaped flowers, each about 2.5 – 5 cm long, appear from leaf axils on the lower stem, then gradually appear up the stem over a period of weeks as the stem keeps elongating (Sheahan, 2014). Depending on the variety, either one or three seed capsules will develop at each leaf axil. Seed capsules are 2.5 to 3.8 cm long, with 8 rows of seeds in each capsule (Sheahan, 2014). Some varieties are branched, while others are un-branched (Myers, 2002). It is propagated by seed and takes about four months for the seeds to ripen fully. The leaves vary from ovate to lanceolate and are hairy on both sides (Anilakumar *et al.*, 2010). There are two types of sesame with regard to pod opening behavior, shattering and non-shattering (dehiscent). Almost all sesame cultivars in Ethiopia are shattering type, which open by cracking of pods from top to bottom and releasing all seeds to fall on ground. The dehiscent varieties have effective seed retention mechanisms, which makes them suitable for machine harvesting or even for traditional but late harvesting (Geremew *et al.,* 2012).

Sesame (*Sesamum indicum* L.) is grown in areas with annual rainfall of 625-1100mm and temperature of >27^0C. It is often grown where cotton can grow, under conditions few other crops can survive, requiring very few inputs (Sheahan, 2014). Sesame is considered as a drought tolerant crop and is therefore mainly grown as dry land crop (Ali and Jan, 2014; Geremew *et al.,* 2012), but not to water logging and excessive rainfall. Sesame is well adapted to a wide range of soils, but requires deep, well-drained, fertile sandy loams (Geremew *et al.,* 2012). Clay soils are more prone to water logging. Sesame will not withstand water over the stem because it limits oxygen presence to the roots and suffocates the plants. Sesame prefers slightly acid to alkaline soils (pH 5-8) with moderate fertility (Zerihun, 2012; Sheahan, 2014). In Ethiopia, sesame grows well in the semi-arid areas of Amhara, Tigray, Benshangul Gumuz, and Somali Regions. Lowlands of Oromiya and Southern Nations Nationalities and Peoples Regions (SNNPR) also grow a significant amount (Geremew *et al.*, 2012).

3.1.2. Importance of sesame

Sesame is grown for its seeds and the primary use of the sesame seed is as a source of oil for cooking. The young leaves may also be eaten in stews and the dried stems may be burnt as fuel and the ash used for local soap making but such uses are entirely subordinate to seed production (Anilakumar, *et al.,* 2010). There are many foods in which sesame is an ingredient. The seeds are used on bread and then eaten in Sicily. Sesame seed has a nutty taste when the seed is roasted. Bread, breadsticks, cookies, chocolate, and ice cream are ideal products for roasted natural sesame seed (Morris, 2002). Sesame seeds add a nutty taste and a delicate, almost invisible crunch to many Asian dishes. They are also the main ingredients in '*tahini*' (sesame seed paste) and the wonderful Middle Eastern sweet called '*halvah*' (Anilakumar *et al.*, 2010).

Sesame is the second largest source of foreign exchange earner after coffee for Ethiopia (Wijnands *et al.,* 2009) as it is the major oil seed in terms of exports in Ethiopia, accounting for over 90% of the values of oil seeds exports (Kindie, 2007). Accordingly, sesame is increasing the potential of generating income for 171,529 farmers in North Gondar administrative zone who have been cultivating sesame on 129,813.34 ha of land in 2007 main cropping season (CSA, 2015).

It is an important source of high quality oil and protein. Roughly half of the seed's weight is its oil, which has excellent stability due to the presence of natural antioxidants such as sesamolin and sesamin (IPGRI and NBPGR, 2004). Sesame oil is mildly laxative, emollient and demulcent. The seeds and fresh leaves are also used as a poultice. The oil has wide medical and pharmaceutical application. Sesamin has been found to protect the liver from oxidative damage. The oil has been used for healing wounds for thousands of years. It is naturally antibacterial for common skin pathogens such as

Staphylococcus and *Streptococcus* as well as common skin fungi such as athlete's foot fungus. (Anilakumar *et al.*, 2010). It is anti-viral and anti-inflammatory. In recent experiments in Holland by Ayurvedic physicians, the oil has been used in the treatment of several chronic diseases including hepatitis, diabetes and migraines (Anilakumar *et al.*, 2010).

3.1.3. Production constraints of sesame

Sesame production in Ethiopia has been increasing extensively in production area from 64,000 ha to 420,494 from 2007 to 2015 (CSA, 2007; CSA, 2015). Despite the country's immense potential to increase sesame production and productivity and significantly increase the international market's demand for sesame, both the production and marketing system of sesame are full of challenges inhibiting the potential for all involved parties. The level of productivity of sesame (seven quintals/hectare) is by far below 50% of the estimated potential of the country and the average productivity level of other sesame-producing countries (Gelalcha, 2009). Among the many production constraints, the most important include a lack of improved cultivars, a poor seed supply system and a lack of adequate knowledge of farming and post-harvest crop management and pests (Gelalcha, 2009). Poor management practices , plant population and spacing, planting methods and diseases and insect pests are described as the main production constrains of sesame in Uganda. Sesame Webworm (*Antigastra catalaunalis*) and Gall midge (*Asphondylia sesami*) are of the most important insect pests of sesame in Eastern and western Uganda whereas Leaf spots and Fusarium wilt are of the most serious diseases (Nakyagaba, 2005).

In Ethiopia there are severe biotic stresses such as Sesame leaf roller or webworm (*Antigasta catalaunalis*) which is an important and widespread insect that damages sesame. The sesame seed bug (*E. sordidus*) is a serious pest causing extensive damage to sesame. It was reported as a post harvest pest of sesame occurring in large numbers on the harvested sesame plants which were heaped for curing in the threshing floor (Selemun, 2011). Bacterial blight (*Xanthomonas campestris* pv. Sesami) is the other important disease of sesame that is the most common and could inflict heavy losses on production (Eshetu *et al*., 1996). Phyllody (Mycoplasma-like organism), Fusarium wilt

(*Fusarium oxysporum*), Powdery mildew (*Oidiumery siphoides*), Alternaria leaf spot (*Alternaria sesame*) and Cercospora leaf spot (*Cercospora sesame*) are also registered pests on sesame (Daniel, 2008).

3.2. Sesame Webworm

Sesame webworm (A. catalaunalis) is an important pest of sesame which is reported to attack sesame in all growth stages (Suliman *et al*., 2013b). At initial stage it webs the upper portion of plant and feed there upon, whereas at flowering stage it feeds on the flowers and at capsule stage it bores into the capsules (Ahirwar *et al.*, 2010). The attack is more sever during dry seasons and after intation of flowering (Suliman *et al*., 2013b).

3.2.1. Taxonomy and distribution

Sesame Webworm, *Antigastra catalaunalis* Duponchel (Pyraustidae: Lepidoptera), is a well-established and widely distributed insect pest of sesame. It can be called sesame leaf roller, sesame capsule borer or sesame leaf webber (Ahirwar *et al.*, 2010; Karuppaiah and Nadarajan, 2013). It is a pest on sesame (*Sesamum indicum*) in the tropics, and it is present in all continents, except Antarctica (Schaffers, 2009). It undergoes a complete metamorphosis that the total lifecycle takes place in 21.26±0.64 days where the eggs incubation period is 2.45 days, while larval period lastes for 10.2± 1.05 days completing five larval instars and pupation occur both inside the webbed leaves and the in the soil. The average pupal period was 4.9±0.21 days and the average adult's longevity is 6.18± 0.2 days. (Suliman *et al*., 2013b).

It is a sporadic pest that causes greatest damage during the seedling and flowering stages, and may continue until harvest, feeding on mature seeds hidden inside capsules. The caterpillar does best in the dry conditions that follow rains, so its development and spread is closely linked to the developing climatic conditions (Geremew *et al.*, 2012).

3.2.2. Importance and damages

Sesame webworm is a pest damaging the crop from seedling to flower and capsule stages at larval stages (Ahirwar *et al.*, 2010). The webworm attacks all parts of sesame, except the roots. It feeds on the tender foliage by webbing the top leaves and also bores into the shoots and pods. It is a serious pest among the 29 insect species attacking sesame in the tropics and subtropics (Narayanan and Nadarajan, 2005). (Ahirwar *et al.*, 2010) reviewed that sesame crop is attacked by 30 species of pests, of which capsule borer, *Antigastra catalaunalis* Dup. is an important pest causing 10-60% yield loss. It pest caused 10 to 70% infestation of leaves, 34 to 62% of flower buds / flowers and 10 to 44% infestation of pods resulting 0 to even 72% yield losses. At initial stage it webs the upper portion of plant and feed there up on, whereas at flowering stage it feeds on the flowers and at capsule stage it bores into the capsules. Thus, 20 to 50 percent losses in yield are caused. Generally, webworm can cause yield losses of between 25% and 35% and critical period for control action is flowering stage. Nevertheless, webworm damage to capsules may inflict up to 100% seed loss (Geremew *et al.*, 2012).One to three larvae are enough to denude a fully grown plant within 24 to 48 hours (Ahirwar *et al.,* 2010).

3.2.3. Biology of sesame webworm

3.2.3.1. Egg

The minute and conical shaped eggs are laid singly on the undersurface of leaves, on capsules and branches. Freshly laid eggs are white in color, which later changed to dark white before hatching. The freshly laid eggs varied from 0.35 to 0.37 mm length and matured eggs measured 0.39 to 0.43 mm. The width of freshly laid eggs varied from 0.18 to 0.19 mm and matured eggs from 0.21 to 0.24 mm (Ahirwar *et al.*, 2010)

3.2.3.2. Larva

The larvae feed on leaves, flowers, pods, and growing shoots. The young larvae mine young leaves and shoot tips; they fasten together leaves and shoots and feed inside. At later stages, the larvae infest the sesame capsules, making an entrance hole on the lateral side (Geremew *et al.,* 2012).

The larvae are the damaging stage in the life cycle of this insect pest. They spin silken webs around terminal leaves, eat the foliage and bore stem sand pods, causing substantial damage to grains inside. First instar larva emerged from the neonate stage is 3.00 to 4.00 mm in length and feed for a little while on the leaf epidermis or within the leaf tissue by scrapping and soon after, bind together the tender leaves of the growing shoot with the help of silken threads while continuing feeding in the webbed mass. Therefore, the larva is also called "leaf webber'' and ''leaf roller". The larvae are very harmful to sesame crop because one plant is infested by 1 to 3 larvae which are enough to destroy it in 24 to 48 hours and it emerges in 4 days on an average to the second instar larva. These larvae have black dots on the abdomen and measure 5.20 to 8.00 mm in length. This instar also feeds on the leaf epidermis, soft part of branches and bores into pods by scrapping for a day on an average, and molts into third instar larva. It has minute brown hair and black dots (setae and tubercles) on the abdomen which were changed in to green setae in 24 hours while molted into the fourth instar. This instar also feeds on the leaf epidermis, soft part of branches, bore into flowers and capsules by scrapping. Full fed larvae are measured to be 13.90 to 14.90 mm in length before the last molt in to the fifth instar larva which measures15.70 to 17.00 mm in length after full growth. In this instar larva, one fine longitudinal line is present dorsally from thorax to the anal segment which feeds mainly on flowers and capsules by scrapping. (Ahirwar *et al.,* 2010).

3.2.3.3. Pupa

Full-grown last instar larvae stop feeding and descend to dry leaves and crevices of the ground for pupation. Pupation takes place in a transparent pale white silken cocoon on a dry leaf or in the surface litter on the ground. Abdominal pro-legs and then thoracic legs are lost. Ultimately head capsule is casted out and pupa is formed (Ahirwar *et al.,* 2010).

3.2.3.4. Adult

Adult moths are stout and have medium size with a wing span of 23.00 to 26.77 mm. The color varies from light reddish brown to dark reddish brown. Forewings are dark reddish brown having dark reddish veins on the upper sides and a series of black dots towards the margins. White dots are present on ventral side of wings just beneath the black dots. Hind wings are transparent (Ahirwar *et al.,* 2010).

3.2.4. Sesame webworm management

Sesame webworm can be managed using different management practices like; varietal resistance, botanical pesticides, cultural practices planting date adjustment and intercropping, natural enemies or using synthetic insecticides. The best integration of these components could give the best result however they have their own contribution for sesame webworm management.

3.2.4.1. Varietal resistance

There are no sesame varieties released for sesame webworm resistance in Ethiopia. But, study results showed that it can be managed through varietal resistance. Study results of Karuppaiah and Nadarajan, (2013) showed the genotypes ES 22, SI 250 and UMA could be a probable source of resistance as they showed non preference, antibiosis mechanisms as well the less damage to *A. catalaunalis*. According to Singh et al. (1990) as cited in (Karuppaiah and Nadarajan, 2013) the genotypes which contained smaller amounts of reducing sugar in the leaves, and higher phenol content in the leaves and flowers showed least damage.

3.2.4.2. Botanical pesticides

Botanical pesticides are biodegradable and are thus considered safer and more environmentally friendly. It is also believed that the botanical insecticides could replace expensive chemicals that are currently in use in many developing countries (Jide-Ojo *et al.,* 2013).The healing power of botanicals has been discussed entirely by scholars who did researches on the plant products for the control of insect pests. Datura, Neem and

Henna are found to reduce the number of *A. catalaunalis* larva infestation and feeding on sesame effectively (Suliman *et al*., 2013a). Research results also showed that Datura water extracts at rates of 10 & 15% was resulted in lowest number of *Antigastra* larvae and Neem and Henna at dosages of 10 and 15% were also given excellent performances when compared with untreated control (Suliman *et al*., 2013a).

Neem (*Azadirachta indica*)

Neem (*Azadirachta indica)* is native to the arid regions of the Indian sub-continent, where it grows to 12-24 m high at altitudes between 50 and 100 m with 130 mm of sufficient rainfall per annum for its normal growth. In India, Neem is known for its use and is more utilized in rice cultivation. Products derived from Neem tree act as powerful Insect Growth Regulators (IGR) and also help in controlling several nematodes and fungi. Neem products reduce insects' growth in crops and plants. Neem products are used as Neem insecticide, Neem pest fumigant, Neem fertilizer, Neem manure, Neem compost, Neem urea coating agent and Neem soil conditioner (Lokanadhan *et al.,* 2012).

Jatropha (*Jatropha carcus*)

Jatropha curcas L. is a widely available tropical plant that often used for fencing by farmers. It has a bio-pesticide potential as extracts of *J. curcas* exhibited anti-feedant and grain protectant effects with the seed oil producing the best results (Jide-Ojo *et al.,* 2013). It has a potential to kill cowpea bruchid adults and it also has ovicidal effects as progeny emergence on treated seeds is decreased significantly (Andargie *et al.*, 2013). (Jide-Ojo *et al.,* 2013) reviewed that the extracts of *Jatropha* showed nematicidal, fungicidal, antifeedant, molluscicidal, and abortifacient activities against white flies (*B. tabaci*), and exhibited insecticidal activities against moths, butterflies, aphids, bugs, beetles, flies, and cockroaches.

3.2.4.3. Planting date adjustment

Pest populations may vary during the growing season, and time of planting can be used to avoid peaks of pest populations. So, combining time of planting with an appropriate minimum insecticide application strategy is most likely going to achieve greater control of the major pests of sesame than relying on either strategy independently. Ali and Jan, (2014) showed that early planting has showed increased yield in Sudan. Planting sesame at the onset of rain combined with application of Cypercal P 720 EC ® twice at 2 and 4 weeks after crop emergence is the most effective strategy of controlling sesame webworm. (Egonyu *et al.*, 2009)

3.2.4.4. Intercropping

Intercropping can also be used as a management practice to sesame webworm as study results revealed that three intercrop arrangements; Intercrop 1 (*S. indicum* and *C. sesamoides* in alternate rows 1:1); intercrop 2 (*S. indicum* and *C. sesamoides* in alternate rows 2:1) and intercrop 3 (*S. indicum* and *C. sesamoides* in alternate rows 1:2) were able to reduce the incidence of *A. catalaunalis* when compared to the sole crop *S. indicum* (Uddin and Adewale, 2014)

3.2.4.5. Natural enemies

Among the parasitoids, unidentified member belonging to the Family Phoridae, Order Diptera and four belonging to the Order Hymenoptera *viz.,Brachymeria (B.) nigricorporis Husain* et Agrawal (Chalcididae), *Doliphocerus gracilis* Hayat (Enchyrtidae), *Tetrastichus sp.* (Eulophidae) and *Eriborus trochanteratus* (Morley) (Ichueumonidae) were found parasitizing the sesame leaf webber (Din-gurs and Hussain, 1997). Besides these, three predators were also noticed. Of these, an unidentified individual (grub) of Order Coleoptera and two more predators of Order Hymenoptera *viz., Eumenes dimidiatepennis* (Eumenidae) and *Polistes chebraeus* (Vespidae) were found predating the leaf roller of sesame (Din-gurs and Hussain, 1997) and *Bacillus thuringiensis* SC at 2 l ha^{-1} control the pest effectively (Geremew *et al.*, 2012).

3.2.4.6. Synthetic insecticides

Insecticides such as Endosulfan 35% EC at 2 l/ha, cypermethrin 20% EC at 4.5 l/ha, lambdacyhalothrin 5% EC at 0.32 l/ha, pirimiphos-methyl 50% EC at 2 l/ha, control sesame webworm effectively (Geremew *et al.,* 2012). Nevertheless, pesticide application should terminate before capsule opening (Geremew *et al.*, 2012). Cypercal P 720 EC ® application at 2 and 4 weeks after crop emergence was found most effective strategy of controlling sesame webworm when combined with planting on the onset of rainfall (Egonyu *et al.,* 2009).

4. MATERIALS AND METHODS

4.1. Description of the Study Area

The study has two parts: a survey on the distribution and damage extent of sesame due to sesame webworm and evaluation of sesame webworm management options. The survey was conducted in four woredas (districts), Metema, *Tach* Armachiho, Tegedie and *Mierab* Armachiho, of North Gondar administrative zone; Amhara region (Fig 1) . The field experiment was conducted in Metema woreda which is located about 900 km North West of Addis Ababa and 180 km west of Gondar town.

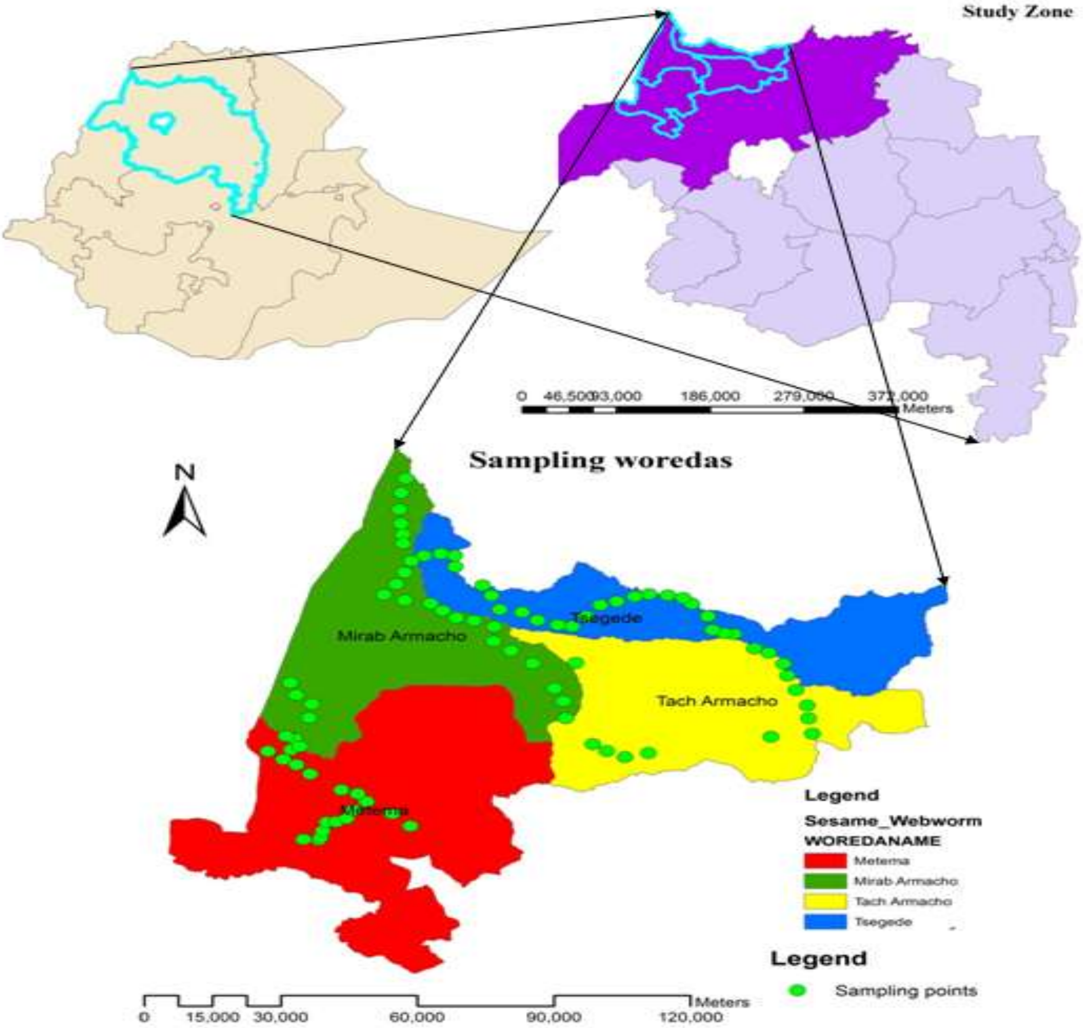

Figure 1. Map of the study area sampling points.

The altitude of Metema district ranges from 550 to 1608 masl and located 12^0 47'N latitude to $38^0$27' longitude (IPMS, 2005).

Tach Armachiho is one of the woredas in North Gondar Administrative zone of the Amhara region of Ethiopia. *Tach* Armachiho is bordered on the south by Lay Armachoho and Chilga, on the southwest by Metema, on the west by *Mierab* Armachiho, on the north by Tegedie, on the east by Dabat and on the southeast by Wogera. Town of the woreda, Sanja, was located 13^o19’60’’ latitude to 36^o44’60’’ longitude. Elevations of the woreda range from 550 to 1600 masl.

Tegedie is also one of the woredas in North Gondar Administrative zone. It bordered on the south by *Tach* Armachiho, on the west by *Mierab* armachiho, on the north by Tigray Region, on the northeast by Debarq, and on the east by Dabat. Town of the woreda, Kirakir, is located $13^0$21’1’’latitude to $37^0$23’9’’ longitude.

Mierab Armachiho is also located in North Gondar North Gondar Administrative zone which is bordered on north and north east by Tigray region, on east by Tegede, on south by Metema, and on west by Sudan. The altitude of *Mierab* Armachiho district ranges from 620 to 850 masl and the town of the woreda, Abrhajira, is located 13^0 28’35’’ latitude to $36^0$28’35’’ longitude.

4.2. Survey on Distribution and Damage due to Sesame Webworm

A field survey of sesame webworm was carried out from August 25 to September 9, 2015 in purposively selected woredas; Metema, *Tach* Armachiho, Tegede and *Mierab* Armachiho, which are major growers of sesame in North Gondar Administrative Zone.

The field survey has followed a systematic sampling procedure, in such a way that sample farmers' fields were examined for incidence of sesame webworm and related parameters; variety, growth stage of sesame, planting date, previous crop, population density, weed density, planting method, cropping pattern, water management practice, soil type and general field condition, in every 3-5 km interval along the road side. The geographical locations of the surveyed fields and altitude in meters above sea level were collected using a portable GPS. Prevalence of the pest was assessed from the described woredas.

A randomly selected sesame fields at the stop points of the survey were assessed for the incidence of the webworm using a 50cm x 50cm quadrat in X- sampling fashion by walking through the field. The assessment was done once in the main growing season. All surveyed localities ranged from 606 to 1189 masl.

4.2.1. Data Collection:

Incidence

Incidence of sesame webworm was calculated as percentage of the ratio of number of plants infested and total number of plants from the average of 3-5 sample (50cm X 50cm) quadrats.

Growth stage of sesame

The growth stage of sesame on the surveyed fields was recorded as; Vegetative, flowering and pod setting.

Planting date:

The planting date was grouped into four periods; early June, late June, early July, and late July.

Population density:

Population density was recorded as dense if more than 10 plants found per $0.25m^2$, medium if 5-10 plants found per $0.25m^2$ and scattered if less than 5 plants found per 0.25 m^2 since the optimum inter and intra row spacing of sesame recommended is 40 cm and 15 cm respectively (Dereje, 2012). With this rate optimum number of seedlings in $0.25m^2$ 5-10 plants. So, below this is termed as scattered and above the optimum is termed dense.

Weed density: Weed density was recorded $<25/m^2$, $25\text{-}40/m^2$ and $>40/m^2$

Planting method: Planting Method was recorded into row planting and broadcasting.

Cropping pattern: cropping pattern was recorded into sole cropping and intercropping.

Water management practice: was recorded into good if the drainage is good and no water logging is occurred, moderate if the drainage moderate and some water logging occurred and bad if there is no drainage of excess water and water logging is a problem.

Soil type: soil type was recorded into vertisol, light sandy, red clay and brown.

General field condition: It was recorded into good, moderate and bad based on the crop stand performance, vigor, and field management.

4.2.2. Data analysis

The descriptive analysis of the data collected from the field survey and the prevalence and distribution of the pest was processed using SPSS version 16. The Association analysis was done using SAS version 9.0.

4.3. Field Experiment on Evaluation of Planting date, Botanicals and Insecticides for the Management of Sesame Webworm

4.3.1. Description of the field experimental site

The field experiment was executed in 2015 main growing season at Metema woreda, in Gondar Agricultural Research Center's Metema sub- center. The site is located at 12°N latitude and 36°E longitude and is about 900 km North West of Addis Ababa and 180 km west of Gondar town. The altitude of Metema wereda ranges from 550 to 1608 masl. The altitude of the station in which the experiment conducted was 761 masl. The mean annual temperature of the station is 28°C. The minimum and maximum temperature is 19.5^0C and 35.7°C, respectively. The mean rainfall for the area ranges from 850 to 1100 mm with a uni-modal rainfall from June to end of September. The dominant soil in the woreda is vertisol and the soil that the experiment was laid was vertisol.

4.3.2. Study Design and Procedure

The field experiment was executed considering natural infestation of sesame webworm. The experimental site was selected purposely in fields at which webworm infestation had been high in the previous cropping season. The experiment was laid in RCB design with three replications. The treatments were composed from factorial combinations of two planting dates, four spray applications (two synthetic insecticides and two botanicals) and unsprayed control (2 x 5 = 10 treatments). Levels of the first factor, planting date, were planting on the onset of rainfall (P1) which practiced by local farmers and late planting (P2), ten days after the first planting date which has also been practiced by the local farmers. Neem kernel aqueous extract spray (I1), Jatropha seed aqueous extract spray (I2), Malathion 50% EC spray (I3), Lamda-cyhaolathrin 5% EC spray (I4) were applied once in two weeks interval starting from the occurrence of pest infestation, one month after planting the first planting date, while the none treated plot (I5) was used for comparison. During spraying high caution was maintained in order to prevent spray drift to the adjacent plots. The local variety ‘Gojjam Azene’ was used to find maximum level of infestation as it is known for being susceptible for sesame webworm from observations from the previous year on experimental plots. Sesame variety ‘Gojjam Azene’ was planted on 2.4m x 5m ($12m^2$) plots having 6 rows. Inter and intra- row spacing was 40cm and 10cm, respectively. The harvestable plot size was $8m^2$ (4 rows) by excluding boarder rows to eliminate the boarder effect. The plots of the first planting date were planted on July 8, 2015 and the plots of the late planting were sown on July 18, 2015. All plots were weeded three times, two weeks after germination, four weeks after germination and eight weeks after germination. Urea fertilizer was applied at the rate of 65 kg/ha in twice; at planting and at flower initiation as per the recommendations of Gondar Agricultural Research Center (GARC). At the time of harvesting, the harvested plants were put in a sack and laid for drying for two weeks with daily follow up and threshed manually with great care to prevent the post harvest loss. The grains were sieved, cleaned and used for measuring yield, thousand seed weight and moisture content. The yield and thousand seed weight were measured using sensitive balance. The moisture content of the seeds, which is used for yield adjustment, was measured using the seed moisture tester having adjusted it using the nationally calibrated moisture tester of Ethiopian Commodity Exchange (ECX). The oil content of sesame was measured at Holeta Agricultural Research Center.

4.3.2.1. List of treatments

Table 1. List of Treatments

Treatment	Description of the treatment	Rate of application
1	Planting July 8 + Neem kernel aqueous extract spray	416.6 L/ha
2	Planting July 8 + Jatropha seed aqueous extract spray	416.6 L/ha
3	Planting July 8 + Malathion spray	2L/ha
4	Planting July 8 + Lamda-cyhaolathrin 5% EC spray	0.32L/ha
5	Planting July 8 + untreated plot	-
6	Planting July 18+ Neem kernel aqueous extract spray	416.6 L/ha
7	Planting July 18+ Jatropha seed aqueous extract spray	416.6 L/ha
8	Planting July 18+ Malathion spray	2L/ha
9	Planting July 18+ Lamda-cyhaolathrin 5% EC spray	0.32L/ha
10	Planting July 18+ untreated plot	-

The treatments were the factorial combinations of the two factors, sowing date and spray applications. The two levels of sowing date and five levels of spray applications result in 2 x 5 = 10 treatments (table 1).

4.3.2.2. Preparation procedure of aqueous extracts

Neem kernel aqueous extraction

Neem (*Azadirachta indica*) seed kernels which were collected at Metema in 2015 were air dried under shed and used for aqueous extract formulation. The neem fruits were removed or de-pulped to obtain the seeds and the seeds were washed thoroughly to remove the dirt and impurity. Then, having dried them, seeds were crushed using mortar and pistil and sieved in 3mm sieve to get fine particles.

The neem kernel powder was then soaked in a bucket of water at a rate of 10% W/V which is 500 g of the powder was soaked in plastic bucket containing 5L water and stirred gently for 30 minutes and then put for 24 hours. The next day the solution was filtered using muslin cloth and the filtrate was and used for making the spray formulation.

Jatropha seed aqueous extraction

Jatropha (*Jatropha carcus*) seeds which were collected at Metema in 2015 were air dried under shed and used for aqueous extract formulation. Jatropha seeds were cleaned, de-shelled and then the kernels and hulls were separated manually. Seeds were crushed using mortar and pistil and sieved in 3mm sieve to get fine particles. The Jatropha seed powder was then soaked in a bucket of water at a rate of 10% W/V which is 500 g of the powder was soaked in plastic bucket containing 5L water and stirred gently for 30 minutes and then put in the laboratory for 24 hours. The filtrate was separated from the crude and used for formulating of the spray solution.

4.3.2.3. Spray formulations and rates of application

The final volume of the plant extract filtrate was made by filtering repeatedly using the muslin cloth. The stickiness and adherence of each of the plant extracts was enhanced by the addition of 5% V/V soap solution as surfactant. Spraying of the plant extracts was done early in the morning because of the photodegradable nature of the extracts. A one liter volume knapsack sprayer was used to apply the 500ml solution on 12m^2 plot.

Malathion 50% EC at the rate of 2 L/ha and Lambdacyhaolathrin 5% EC at the rate of 320 ml/ha was applied using 200L water per hectare for dilution.
The spray treatments were applied using a calendar based spray procedure. The first spray was made one month after planting after recording incidence of sesame webworm in every plot. The subsequent sprays were made in two weeks interval for one month.

4.3.3. Data collection

Webbed plants percentage (WPP) was recorded before and after treatment application in plot basis by counting total number of plants and infested plants (plants whose shoots were rolled by webworm) from the central rows of a plot. Stand count at emergence and harvest; days to flowering, days to maturity and spraying dates, was also recorded from the central rows of a plot. Plant height, number of capsules per plant, damaged capsules per plant, number of seeds per capsule, damaged branches per plant, grain yield, thousand seed weight, moisture content, oil content, and relative yield loss were recorded.

Plant height, number of capsules per plant, damaged branches per plant and damaged capsules per plant

The above parameters were recorded by calculating the average from the results of five randomly selected sample plants in a plot from the central rows. Plant height was measured in centimeters, number of capsules per plant was expressed in number and damaged branches per plant and damaged capsules were expressed in percentages.

Number of seeds per capsule

Number of seeds per capsule was recorded by using the average number of seeds from randomly selected five capsules of five plants from the central row plants.

Thousand seed weight

This was measured in grams by weighting 1000 randomly selected seeds in a plot.

Moisture content

The moisture content was measured in percentage using a moisture calibrated moisture meter.

Grain Yield

Grain yield was recorded in grams per plot from the yield of the central row plants at 8% moisture content and then it was converted into kilograms per hectare.

Relative yield loss and capsule loss

According to (Takele *et al*, 2015) the relative yield losses were computed as per the equation;

$$\boldsymbol{RL}\% = \left(\frac{(\boldsymbol{Y_1} - \boldsymbol{Y_2})}{\boldsymbol{Y_1}}\right)\mathbf{100}$$

Where:

RL- relative loss (reduction of the parameters yield and yield components)

Y1- mean of the respective parameters in protected plot (plots with maximum protection)

Y2 –mean of the respective parameters in unprotected plots.

4.3.4. Data analysis

The Analysis of Variance (ANOVA) and mean separation and comparison was carried out by Least Significant Difference (LSD) at $\alpha = 0.05$ probability level using SAS-GLM procedure of SAS version-9 software. The correlation of the dependant variables was also analyzed using SAS CORR procedure.

Data of damaged capsule per plant was subjected to square root transformation as the CV in the untransformed data was higher (Gomez and Gomez, 1984). The transformed values are displayed in bracket with the actual values.

The association of sesame webworm incidence with independent variables was analyzed using logistic regression using SAS version 9.0 GENMOD procedure. The logistic regression model assesses the importance of multiple independent variables that affect the response variable. It calculates the probability of a given outcome as a function of the independent variables. The SAS procedures GENMOD and logistic were used to estimate the parameter estimates. Exponentiation the parameter estimates of each variable class results the odds ratio, which are interpreted as relative risk. The importance of the independent variables (risk factors) was evaluated with the association of an independent variable alone with sesame webworm incidence. Deviance reduction was calculated for each variable as it was added to the reduced model and likelihood ratio test was used to examine the importance of the variable and was tested against $\chi 2$- value (McCullagh and Nelder, 1989).

Cost and benefit assessment

Cost and benefit assessment was calculated for the early planting since it has given highly significant yield than late planting and late planning has 82% loss (Table 5) relative to early planting so that its MRR was not calculated.

Price of sesame seed per kg, total seed cost for one hectare, price of insecticides, price of botanicals, formulation material cost, cost of labor for spray and spray equipment rented was considered. Price of grain (Birr kg^{-1}) was obtained from local market and total sale from one hectare was computed.

Based on the data, cost benefit analysis was performed using partial budget analysis which is employed to assess profitability of any new technologies to be imposed to the agricultural business (CIMMYT, 1988).

To measure the increase in net return associated with each additional unit of cost (marginal cost), the marginal rate of return (MRR) was calculated as:

$$\boldsymbol{MRR} = \frac{\Delta \boldsymbol{NI}}{\Delta \boldsymbol{IC}}$$

Where, MRR is marginal rate of returns, ΔNI – change in net income compared with control, ΔIC – change in input cost compared with control.

The following points were considered during cost benefit analysis using partial budget.

- Costs for sesame seed, agronomic practices were uniform for all treatments.
- Labor costs and equipment are considered as per the price of the locality
- The of costs, benefit and return was calculated per hectare basis
- Farmers in the area were assumed to obtain 85% of the yield in the research field and the yield was adjusted based on this percentage.

5. RESULT AND DISCUSSION

5.1. Field Survey of Sesame Webworm

5.1.1. Prevalence, incidence and frequency of sesame webworm distribution

5.1.1.1. Prevalence

Prevalence of sesame webworm in North Gondar Administrative zone was 89.9%. Of the 90 fields surveyed, only one field in *Tach* Armachiho was found free from sesame webworm infestation. This indicates that the distribution of sesame webworm was high in North Gondar and the pest is a potential constraint for sesame production (Karuppaiah, and Nadarajan, 2013). No matter how the level of infestation is different its high prevalence can cause high loss in favorable conditions.

5.1.1.2. Incidence of sesame webworm

Incidence of sesame webworm in North Gondar ranges from 0% to 100%. Of the surveyed fields, 73 fields (81.1%) had less than or equal to 50% incidence and 17 fields (18.9%) had incidence greater than 50. Only one field had no infestation and 10 fields had 100 % incidence. In such cases of sever infestation it could cause higher losses which could inflict pod damage up to 100% (Geremew *et al*., 2012).

From the 90 farmers' fields surveyed, 30 fields were in Metema woreda where 27 had incidence less than 50%, 15 fields were in Tach Armachiho where 10 fields had incidence less than 50%, 23 fields were in Tegedie where 18 fields had incidence less than 50% and 22 fields were in *Mierab* Armachiho where 18 fields had incidence less than 50% (Table 2).

Table 2. Number of surveyed fields in variable classes and incidence of sesame webworm below and above 50%.

Variable	Variable classes	Total Number of fields	Number of fields	
			Incidence	
			< (=) 50%	>50%
Variety	Local	80	66	14
	Improved	10	7	3
Woreda	Metema	30	27	3
	Tach Armachiho	15	10	5
	Tegedie	23	18	5
	Mierab Armachiho	22	18	4
Altitude	< (=) 700	17	15	2
	>700	73	58	15
Growth Stage	Vegetative	40	29	11
	Flowering	42	38	5
	Pod setting	7	6	1
Planting Date	Early June	6	5	1
	Late June	13	12	1
	Early July	36	32	4
	Late July	35	24	11
Population Density	Dense	34	27	7
	Medium	48	40	8
	Scattered	8	6	2
Weed Density	>40/m^2	11	8	3
	25-40/m^2	43	33	10
	<25/m^2	36	32	4
Soil Type	Vertisol	49	39	10
	Light sandy	18	17	1
	Red clay	21	15	6
	Brown	2	2	0
Field condition	Good	18	15	3
	Moderate	58	46	12
	Bad	13	12	2
Water management	Good	32	27	6
	Moderate	47	38	9
	Bad	10	8	2

< (=) 50%= incidence less than or equal to 50%, > 50% = incidence greater than 50%

5.1.1.3. Frequency and descriptive of variables

At the time of survey, 44.4% of the fields were at vegetative stage, 47.8% of the fields were at flowering stage and 7.8% of the fields were at pod setting stage. Of the fields surveyed 6.7% were planted early June; 14.4% late June; 40% early July and 38.9% late July (Figure 2) and values for weed density, cropping pattern, planting method, water management and soil type are described in table 3.

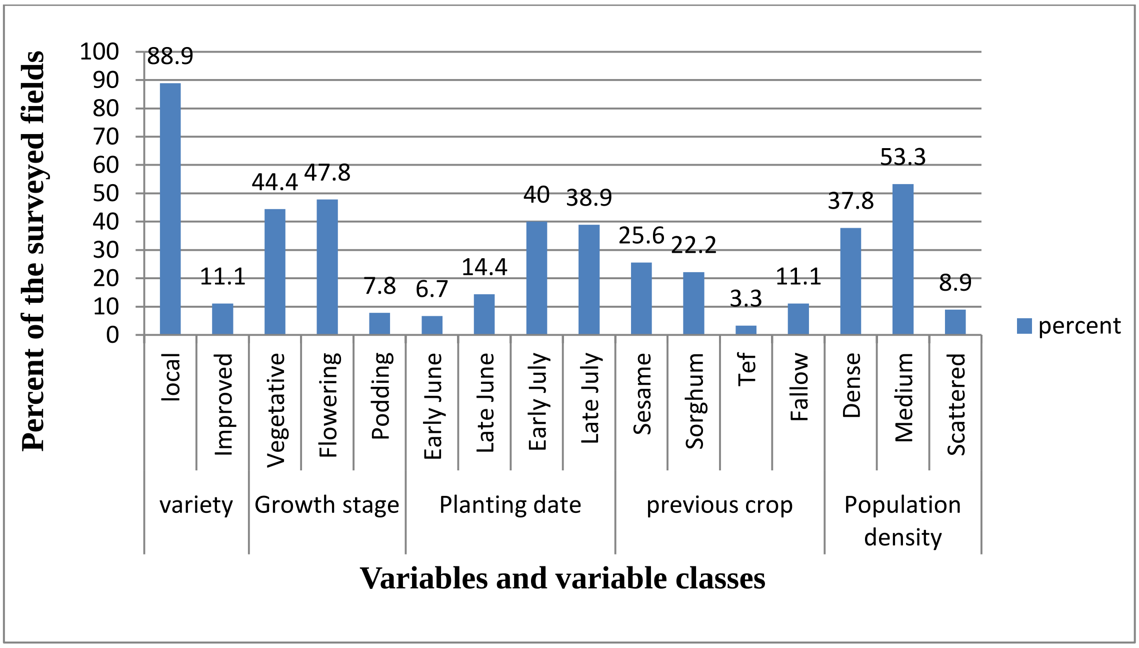

Figure 2. Frequency of variety, growth stage, planting date, previous crop and population density distribution

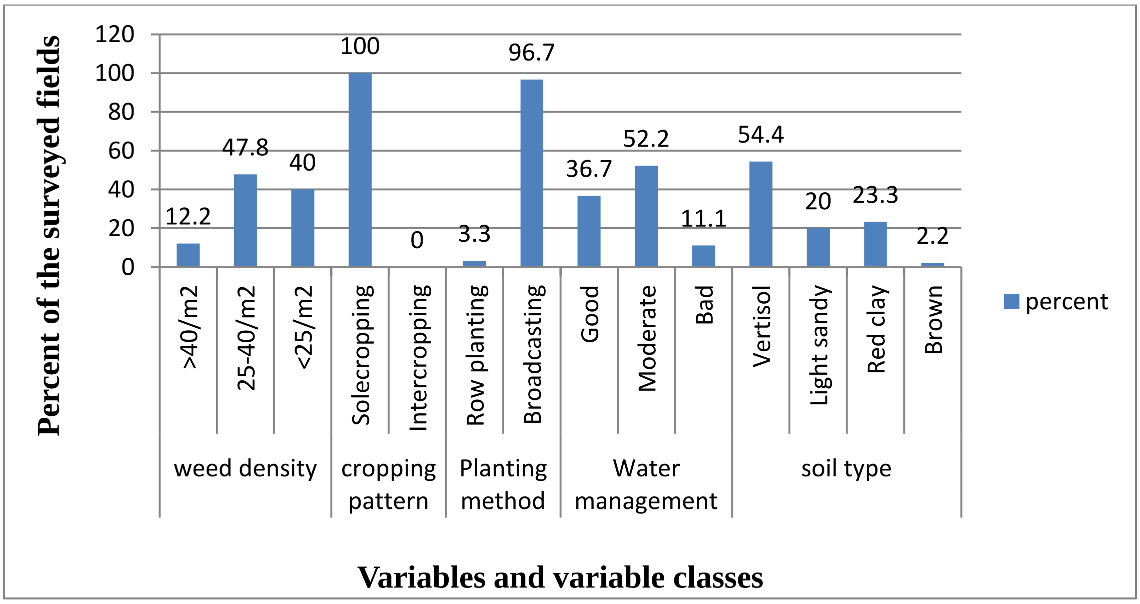

Figure 3. Frequency of weed density, cropping system, cropping pattern, drainage and soil type distribution

5.1.2. Association of independent variables with sesame webworm incidence

The association of the independent variables, variety, woreda, altitude, growth stage, planting date, population density, weed density, and field condition with incidence of sesame webworm was highly significant as Pr> χ^2 is <0.01 (Table 3). This implies that all the described independent variables were risk factors and the different variable classes have showed different risk levels for the sesame webworm occurrence. All the described independent variables (Table 3) were tested in a reduced multiple variable models with sesame webworm incidence as the dependent variable. For added variables analysis of deviance, parameter estimates, standard errors resulting from the reduced regression model are given in Table 4.

Table 3. Logistic regression modeling of sesame webworm incidence and Likelihood Ratio Test (LRT) for 9 independent variables as a single predictor of pest infestation outcome.

Independent variable	df	DR	χ^2	Pr > χ^2
Variety	1	3945	34.09	<.0001
Woreda	3	3288	656.13	<.0001
Altitude	1	2795	493.82	<.0001
Growth stage	2	2780	14.59	0.0007
Planting date	3	2738	42.03	<.0001
Population density	2	2724	13.65	0.0011
Weed density	2	2673	51.59	<.0001
Soil type	3	2624	48.68	<.0001
Field condition	2	2501	123.54	<.0001

df = degree of freedom, DR = deviance reduction, Pr = probability of χ^2 value exceeding the deviance reduction

Improved varieties had higher association with sesame webworm than the local varieties (Table 4). This means improved varieties have showed more probability of being infested by sesame webworm than the local varieties. This reason behind might be due to the that improved sesame varieties distributed in the locality, 'Abasena' and 'Humera 1' were not released for the control of sesame webworm rather, the target was mainly for yield. The insect pest has highly significant association to Metema and *Mierab* Armachio woredas than Tach Armachiho and Tegedie. This result could probably be the result of one or more added variables which can describe the features of the woreda. However, the two woredas have showed higher risk of sesame webworm infestation (Table 4). Altitudes less than or equal to 700 have showed less association with sesame webworm incidence whereas those locations above 700 masl have showed high association with sesame webworm incidence (Table 4). So, sesame webworm is less likely to infest fields with altitudes less than 700 masl. The capsule setting stage was found to have showed high association with sesame webworm incidence. This agrees with the result of (Talpur *et al*., 2002) that states significantly greater damage of sesame webworm at capsule formation stage than vegetative growth and flowering stage. Pod/capsule setting stage is the stage at which the cumulative effect of infestation is reflected and its higher association with incidence reveals the ability of sesame web worm to attack sesame at all growth stages of the crop and the attack is higher at capsule setting stage (Ahirwar *et al.,* 2010, Suliman *et al* 2013b). The pod setting stage usually overlies with planting in early July which had significantly higher association with sesame webworm incidence than planting in June that has showed no significant association with webworm incidence (Table 4). In other words, planting on the onset of rainfall has showed less risk of infestation than late planting which agrees with the result of (Egonyu *et al.*, 2009)

Fields with high population density, fields that had more than 10 plants per $0.25m^2$, have showed higher association with webworm incidence than medium populated and scattered fields odds ratio = 1.08 (Table 4). Densely populated plants are known to be less vigorous and the leaf diameter and area of such plants is small. Infestation and webbing process were influenced by leaf area (Suliman *et al.*, 2013b) which is the secret behind high association of sesame webworm with densely populated fields. Fields that had weed density $>40/m^2$ have showed significantly higher association with sesame webworm incidence odds ratio = 1.66 and $P < 0.001$ (Table 4). This is an indication that weeds aggravate webworm infestation significantly because they serve as alternate host for insect pests (Geremew *et al.*, 2012). Weeded plots have showed no significant association with webworm incidence. Brown soil has showed greater association with the incidence of webworm than vertisol, light sandy and red clay soils which have showed significant but lower association with sesame webworm incidence.

Table 4. Analysis of deviance, natural logarithms of odds ratio, odds ratio and standard error of added variables in a reduced model predicting sesame webworm incidence.

Added Variable	df	LRT		Variable class	Estimate $Log_e(OR)$	SE	Odds ratio	χ2
		DR	Pr > χ2					
Intercept		3978.6	<.0001		2.86	0.38	17.49	56.57
Variety	1	3944.5	0.0004	Local	-0.31	0.09	0.73	12.41
				Improved	0.00	0.00	1.00	
Woreda	1	3288.4	<.0001	Metema	-2.30	0.10	0.10	561.02
	1		<.0001	*Tach* Armachiho	-2.93	0.12	0.05	606.50
	1		<.0001	Tegedie	-1.09	0.09	0.34	140.32
				Mierab Armachiho	0.00	0.00	1.00	
Altitude	1	2794.6	<.0001	< (=) 700	-1.73	0.09	0.18	360.58
				>700	0.00	0.00	1.00	
Growth Stage	1	2780	0.4244	Vegetative	-0.27	0.34	0.76	0.64
	1		0.3066	Flowering	-0.34	0.33	0.71	1.05
				Pod setting	0.00	0.00	1.00	
Planting Date	1	2738	0.3332	Early June	0.35	0.36	1.41	0.94
	1		0.1152	Late June	0.18	0.11	1.19	2.48
	1		<.0001	Early July	0.49	0.11	1.63	21.71
				Late July	0.00	0.00	1.00	
Population Density	1	2724.3	0.4675	Dense	0.07	0.10	1.08	0.53
	1		0.2525	Medium	-0.12	0.11	0.89	1.31
				Scattered	0.00	0.00	1.00	
Weed Density	1	2672.7	<.0001	$>40/m^2$	0.51	0.09	1.66	32.93
	1		0.1014	$25-40/m^2$	0.10	0.06	1.10	2.68
				$<25/m^2$	0.00	0.00	1.00	
Soil Type	1	2624.1	<.0001	Vertisol	-1.02	0.19	0.36	29.09
	1		<.0001	Light sandy	-1.11	0.19	0.33	32.48
	1		0.0015	Red clay	-0.61	0.19	0.54	10.06
				Brown	0.00	0.00	1.00	
Field Condition	1	2500.5	<.0001	Good	-0.90	0.10	0.41	81.04
	1		<.0001	Moderate	-0.79	0.07	0.46	116.78
				Bad	0.00	0.00	1.00	

df = degree of freedom, DR = deviance reduction, Pr = Probability of χ2 value exceeding the deviance reduction, SE = standard error, LRT = likelihood ratio test, χ2 = Chi-square

Fields that were not managed well, fields with bad general condition, have showed higher association with sesame webworm which implies the webworm infested fields were less managed fields in terms of different agronomic practices.

5.2. Field Experiment on Management of Sesame Webworm

5.2.1. Analysis of variance

The results of the ANOVA (Table 5) showed highly significant response of the planting dates on yield and yield parameters; number of capsules per plant, number of seeds per capsule, plant height, thousand seed weight, grain yield, and oil content. But the spray applications have showed no statistically significant difference in number of capsules per plant, number of seeds per capsule, plant height, thousand seed weight, grain yield, and oil content

Table 5. ANOVA table of the main effects in yield and yield parameters

Planting dates	Number of capsules per plant	Number of seeds per capsule	plant height (cm)	Thousand seed weight (g)	Grain yield (kg/ha)	Relative yield loss (%)	Oil con tent (%)
Early planting	60.57b	70.03b	171.35b	2.299b	1172.4b	0.0	53.55b
Late planting	30.68a	77.4a	140.25a	1.995a	200.1a	82.9	49.79a
LSD (5%)	6.43	5.72	5.6	0.08	154.1		0.65
Pr > F	**	*	**	**	**		**
Spray application							
Neem extract	50.633	71.37	160.3	2.17	758.5	0.7	51.04
Jatropha extract	39.433	74.57	149.3	2.21	569.9	25.4	51.65
Malathion 50% EC	47.7	70.1	155.1	2.11	764.1	0.0	51.56
Lambdacyhaolathrin 5%	48.3	76.83	156.93	2.09	653.5	14.5	52.53
Untreated control	42.07	75.7	157.37	2.16	685.1	10.3	51.56
LSD(5%)	NS	NS	NS	NS	NS		NS
Pr > F	NS	NS	NS	NS	NS		NS
Grand mean	45.63	73.71	155.8	2.15	686.24		51.67
CV%	18.38	10.12	4.94	4.99	13.79		1.64

** significant at α=0.05, ** significant at α=0.01*

Interaction of the two factors, planting date and spray applications was not statistically significant at 5% level of significance. Early planted plots have showed more number of capsules ($p < 0.01$) than the late planted plots. Early planting has resulted in significantly longer ($P < 0.01$) sesame plants than late planting.

In case of number of seeds per capsules the late plots have resulted in significantly more ($P < 0.05$) seeds per capsule than those of the early planted plots which could have contributed to found significantly lower ($P < 0.01$) thousand seed weight.

Early planting had resulted in significantly higher ($P < 0.01$) yield than late planting (Table 5). This is the same with the result of (Ali and Jan, 2014) that showed increased yield of early planting in Sudan. Accordingly, late planting has resulted in 82.9% yield loss relative to the early planting. Planting early has given significantly higher oil content ($P < 0.01$) than planting 10 days later (Table 5).

There is no significant difference at ($\alpha = 0.05$) among the spray applications including the control on yield and yield parameters however, spraying Malathion 50% EC has showed yield advantage ranging from 0.7% to 25% than other spray applications and the control (Table 5). Webbed plants percentage (WPP) of sesame webworm infestation in early planted plots was significantly lower than the late planted plots before the first spray application (Table 6). This indicated that planting in different planting dates has resulted in significantly different infestation levels which can be used as control measure against sesame webworm. (Egonyu *et al.*, 2009) also recommended planting on the onset of rainfall for the control of sesame webworm. There is also highly significant difference ($P<0.01$) between early planting and late planting in percentage of webbed plants after the first and the second sprays (Table 6).

Percentage of webbed plants before the first spray, after the first spray, and after the second spray was 18.5, 15.2% and12.7 respectively in late planting and 56.1, 62.3 and 70.7 respectively in late planting. Spraying insecticides in sever infestations has showed no advantage in reducing the infestation since the larva is hidden in the webbed leaves (Suliman *et al.*, 2013b) that cannot be reached with contact insecticides. However, there was no significant difference among different sprays after the first spray application. The difference in percentage of webbed plants was highly significant for planting date and spray application after the second spray. The interaction was also highly significant after second spray application (Table 6).

Table 6. ANOVA table of the main effects in WPP and sesame webworm damage parameters.

Planting date	Webbed plants before 1st spray (%)	Webbed plants after 1st spray (%)	Webbed plants after 2nd spray (%)	Damaged branches per plant (%)	Damaged capsules per plant (%)
Early planting	18.5b	15.2b	12.7b	68.97b	3.2(1.75)b
Late planting	56.1a	62.3a	70. 7a	98.32a	12.4(3.4)a
LSD (5%)	7.9	5.03	5.63	14.03	2.59(0.37)
Pr>F	**	**	**	**	**
Spray application					
Neem aqueous spray	38.67	38.1	36.67c	90.13	7.75(2.65)bc
Jatropha aqueous spray	36.5	40.25	45.83ab	78.17	7.75(2.62)ab
Malathion 50% EC	36.83	37.5	40c	75.45	7.12(2.5)bc
Lambdacyhaolathrin 5% EC	37.17	35.32	35c	85.33	5.00(2.11)c
Untreated control	37.17	42.65	50.83a	89.14	11.44(3.07)a
LSD (5%)	NS	NS	8.9	NS	4.10(0.59)
Pr>F	NS	NS	**	NS	*
Grand mean	37.27	38.76	41.7	83.64	8.79
CV%	27.6	16.9	17.6	21.9	18.8

** significant at α = 0.05, ** significant at α =0.01*

Damaged branches percentage per plant and damaged capsules per plant of the late planted plots were significantly higher (P<0.01) than those of the early planting plots. But, there is no statistically significant interaction between the factors in capsule damage percentage and the other parameters (Table 6). Number of damaged capsules per plant was also significantly different (P<0.05) among spray treatments where Neem aqueous spray, Lambdacyhaolathrin 5% EC and Malathion 50% EC have resulted in significantly lower WPP than the Jatropha sprayed and the control (Table 6). There was no interaction among the two factors; however the main effects have showed statistically significant responses. The untreated control and Jatropha sprayed plots have inflicted significantly higher (P< 0.01) percentage of damaged capsules per plant than the other spray applications. Lambdacyhaolathrin 5% EC and Neem aqueous spray have resulted in significantly lower WPP than the other treatments. (Geremew *et al.,* 2012) has stated sesame webworm can be controlled using Lambdacyhaolathrin 5% EC and (Suliman *et al.,* 2013a) revealed effective control of sesame webworm using Neem.

Result of spray applications had no interaction with the planting dates. Therefore, by planting early at the onset of rainfall, pod damage percentage can be reduced by 74% relative to the untreated control which is from 12.44% to 3.18%. Similarly spraying lambdacyhaolathrin has reduced pod damage from 11.4% to 5% (Table 6).

Table 7. Interaction of planting date and spray application on WPP after 2nd spray

Treatment number	**Treatments**	WPP **after 2nd spray (%)**
1	Early planting (P1) + Neem aqueous spray(I1)	8.43d
2	Early planting (P1) + Jatropha aqueous spray (I2)	15.07d
3	Early planting (P1) + Malathion (I3)	10.07d
4	Early planting (P1) + Lamda-cyhaolathrin 5% EC (I4)	16.77d
5	Early planting (P1) + Untreated plot (I5)	13.37d
6	Late planting (P2) + Neem aqueous spray (I1)	64.77ab
7	Late planting (P2) + Jatropha aqueous spray(I2)	76.5ab
8	Late planting (P2) + Malathion (I3)	70.1bc
9	Late planting (P2) + Lamda-cyhaolathrin 5% EC (I4)	53.5cd
10	Late planting (P2) + Untreated (unsprayed) plot (I5)	88.5a
	Grand mean	41.71
	CV%	17.3
	LSD (5%)	12.37
	Pr > F	**

WPP – Webbed Plants Percentage

The interaction has revealed that treatments 1, 2, 3, 4, 5, 9 have showed significantly lower sesame webworm WPP than treatments 6, 7, 8, 10. Treatment 10, late planted and unsprayed, has inflicted the highest WPP and treatment 1, early planting and neem aqueous spray has showed lower WPP after the second spray application (Table 7) This agrees with the results of (Egonyu *et al.*, 2009) and (Suliman *et al.*, 2013a). Therefore, planting early and spraying chemicals has reduced the WPP of sesame webworm significantly in two consecutive sprays in two weeks interval.

5.2.2. Correlation of dependent variables

The parameter, number of capsule per plant (NCP) has showed no correlation with number of seeds per capsule but has showed significant ($P<0.01$) and strong positive correlation with plant height, thousand seed weigh, grain yield, and oil content however it has showed significantly (P<0.01) strong negative correlation (r = -0.74, -0.84, -0.86, -0.77) with WPP before spray, after the first spray, after the second spray and capsule damage percentage, respectively. It has showed also negative and weak but significant correlation with branch damage percentage (Table 8). One of the physiological influences of sesame webworm is on the plant height as it mainly webs the growing tip and hinders the growth. This has coincided with the correlation value of plant height with WPP before spray and after the first and second sprays (Table 8) which is highly significant (P<0.01), negative and strong (r = -0.73, -0.87, -0.92).

Table 8. Correlation of dependent variables

	NCP	NSC	PH	TSW	YLD	WPP1	WPP2	WPP3	BDP	CDP	OC
NCP	-										
NSC	-0.41	-									
PH	0.84**	-0.46**	-								
TSW	0.74**	-0.4*	0.77**	-							
YLD	0.92**	-0.5**	0.94**	0.82**	-						
WPP1	-0.74**	0.41*	-0.73**	-0.77**	-0.78**	-					
WPP2	-0.84**	0.54**	-0.87**	-0.80**	-0.89**	0.95**	-				
WPP3	-0.86**	0.56**	-0.92**	-0.79**	-0.91**	0.84**	0.96**	-			
BDP	-0.47**	0.28ns	-0.58**	-0.47**	-0.54**	0.62**	0.65**	0.61**	-		
CDP	-0.77**	0.52**	-0.71**	-0.69**	-0.77**	0.75**	0.84**	0.87**	0.43*	-	
OC	0.72**	-0.34ns	0.7**	0.69**	0.74**	-0.91**	-0.91**	-0.84**	-0.59**	-0.80**	-

NCP = number of capsules per plant, NSC = Number of seeds per capsule, PH = plant height, TSW = thousand seed weight, YLD = grain yield, WPP1 = Webbed Plants Percentage before spray treatment application, WPP2 = Webbed Plants Percentage after 1st spray, WPP3 = Webbed Plants Percentage after 2nd spray, BDP = branch damage percentage, CDP = capsule damage percentage, OC = oil content

Plant height has showed significant and very strong positive correlation with yield (r = 0.94). The effect of sesame webworm on plant height, since it webs the growing tip, affects the yield indirectly as plant height has strong negative correlation with of webbed plant Percentages before spray, after the first spray and after second spray applications (r = -0.73, -0.87, -0.92) respectively. Thousand seed weight has showed significantly (P<0.01) strong negative correlation with the WPP before and after spray. It has also showed significant negative correlation with branch and capsule damage percentages (Table 8). WPP of sesame webworm before spray and after the first and the second sprays has showed highly significant (P<0.01) and strong negative correlation with oil content (r = -0.91, -0.91, -0.84). This implies that the effect of sesame webworm is not only quantitatively; rather it has showed high influence on the quality of sesame, in this case the oil content, because its incidence is higher at capsule setting stage (Ahirwar *et al.*, 2010).

5.2.3. Cost Benefit Analysis

The partial budget analysis showed that spraying neem aqueous extract (Treatment 3) has resulted in the highest net profit in the early planted plots. This has also resulted in statistically insignificant webbed plants percentage with treatments 1, 2, 4, 5 and 9 and statistically lower webbed plants percentage than treatments 6, 7, 8 and 10 (Table 7). In early planting, application of spray treatments Neem aqueous extract, Jatropha aqueous extract, and Lamdacyhaolathrin resulted in loss of birr 3827.5, 10889.3 and 6084.1 per hectare respectively over the untreated check. The respective MRR of the spray applications; Neem extract, Jatropha extract, Malathion and lambdacyhaolathrin was -61.2, -261.1, 307.2 and -5432.2 (Table 9). Early planting has given significantly higher grain yield than late planting, however, it is not economically profitable if any spray treatment is applied except Malathion 50% EC.

The highest input cost of Neem and Jatropha aqueous spray preparation account for the loss. The input cost is higher due to the reason that price of botanical seeds is high and the preparation is time consuming and requires more labor than the use of chemical insecticides (Childs et al, 2001).

Table 9. Partial budget analysis insecticide sprays for sesame webworm management at Metema in 2015 for early planting

No.	**Cost Benefit calculation Early planting**	**Treatments**				
		1	2	3	4	5
1	Adj yield(Kg/ha)(Y x 0 .85)	1136.8	832.1	1100.8	857.0	1056.0
2	sesame price (Birr/kg)	30.0	30.0	30.0	30.0	30.0
3	Sale revenue (1 x 2)	34103.7	24962.0	33025.1	25709.1	31681.2
4	Total input cost (Birr ha^{-1})	6250.0	4170.0	330.0	112.0	0.0
5	Marginal Cost (Birr ha^{-1})	6250.0	4170.0	330.0	112.0	0.0
6	Net profit (3-4)(Birr ha^{-1})	27853.7	20792.0	32695.1	25597.1	31681.2
7	Marginal Benefit (Birr ha^{-1})	-3827.5	-10889.3	1013.9	-6084.1	0.0
8	MRR (7/5) (%)	-61.2	-261.1	307.2	-5432.2	-

Adj yield = yield adjusted to the farmers' yield

6. SUMMARY AND CONCLUSIONS

Sesame (*Sesamum indicum* L.) is one of the most important export crop for Ethiopia thereby increasing the export earning of the country and improving the livelihood of the local population. In the last few years, sesame production has shown growth extensively in production area and also increased market value. However, it shows some decrement in production area and market value in the last year. This might be accounted for different attributes and besides this, a wide range of pests attack sesame around the world and of these pests sesame webworm, (*A. catalaunalis*) is one of the most important pests since it was reported to attack the crop in all growth stage. Due to these pests and repeated occurrence of sesame webworm, farmers use insecticides of lower cost intensively which have showed potential of challenging our sesame marketing and known to cause lots of consequences for human, living environment. To solve the potential problem of insecticides, to manage sesame webworm and to establish sustainable sesame production and marketing system, non chemical sesame webworm management options or chemicals with the least hazard should be chosen.

A field survey was carried out in ninety fields to assess the prevalence of sesame webworm in North Gondar Administrative zone main production areas, Metema, Tach Armachiho, *Mierab* Armachiho and Tegedie woredas and a field experiment aiming to find a management option for sesame webworm with 10 treatments were executed.

The survey revealed that all independent variables have showed significant association with the webworm incidence. This means all variables were risk factors for webworm incidence. According to the result of association analysis, improved varieties, elevations greater than 700 masl, planting in early July, high population density, and weed density $>40/m^2$ have showed high association with sesame webworm incidence. Planting in June has showed insignificant association with webworm incidence where as planting in July has significant association. This revealed planting early on June has advantage of minimizing webworm infestation risk. This, basically, coincides with the result of the field experiment which has showed the superiority of early planting in minimizing webworm infestation. The commutative effects of these resulted in high risk of sesame webworm infestation in Metema and *Mierab* Armachiho.than *Tach* Armachiho and Tegedie.

The reason behind the risk factors effect on the incidence of sesame webworm should be studied in further and detail separate studies, however these risk factors can help to manage sesame webworm in some part. For instance, planting in early July was found to high risk of sesame webworm incidence than planting in June. This result actually agrees with the field experiment and with the result of (Egonyu *et al.,* 2009). The field experiment result showed planting on the onset of rainfall was found significantly superior ($P<0.01$) in number of capsules per plant, plant height, thousand seed weight, grain yield. Early planting has also resulted in significantly low ($P<0.01$) WPP before and after treatment application, percentage of damaged branches and capsules. The two factors have showed interaction in case of WPP after 2nd spray and early planting with neem aqueous spray (treatment 1) has resulted in significantly lower ($P<0.01$) WPP (8.43%) than treatments 6, 7, 8, 9, 10 and treatment 10, late planting and unsprayed control, has resulted in significantly high ($P<0.05$) WPP (88.5%) than all other treatments.

According to the results, planting sesame on the onset of rainfall is advantageous to let it escape the sesame webworm infestation at a very early stage of the crop. As the late planting had higher chance of exposure to sever infestation of sesame webworm at early seedling stage the crop, the effect of damage had been significantly expressed in the yield. Therefore, sesame should better be planted as soon as possible after the onset of rainfall.

Sesame webworm WPP has shown highly significant strong correlation with the oil content which is an indication to the effect of sesame webworm on the quality of sesame. Therefore, the effect of sesame webworm on quality should also be considered if no yield difference is found between webworm infested and webworm free fields.

The effect of spraying insecticides is advantageous in reducing the WPP of sesame webworm; however there is no significant effect on yield. The partial budget analysis has showed losses in spraying Neem extract, Jatropha extract and Lambdacyhaolathrin 5% EC with early planting. Despite early planting with Neem aqueous extract resulted in lower webbed plants percentage, early planting with Malathion spray has given the highest MRR. The economic loss due to Neem and Jatropha aqueous extract sprays is basically accounted for high preparation cost of botanicals which could possibly be alleviated due to the availability of commercial production of Neem extracts on market like *Nimbicidine* with much lower prices (about 500 birr per liter). This must further be investigated so as to boost organic sesame production and help to attain sesame webworm management with non chemical options.

Therefore, it is recommended to plant sesame at the onset of rainfall and spray with Malathion 50% EC at a rate of 2 L/ha twice in two weeks interval for effective control of sesame webworm.

Further and detail studies of sesame webworm biology with the support of many years meteorological data and detail field surveys are suggested to find more precise and appropriate planting date.

In addition, further study on the efficacy of commercial products of neem with cost benefit analysis is also important since neem showed promising result in sesame webworm management regardless of its economical loss.

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APPENDICES

Appendix 1. Analysis of variance of number of capsules per plant

Source of variation	DF	Sum of squares	Mean Square	F Value	Pr > F
Planting date	1	6702.085333	6702.085333	95.31	<.0001**
Spray	4	525.258667	131.314667	1.87	0.1601
Planting date*spray	4	408.714667	102.178667	1.45	0.2576

**Highly significant

Appendix 2. Analysis of variance of number of seeds per capsule

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	407.7453333	407.7453333	7.34	0.0144*
Spray	4	197.8346667	49.4586667	0.89	0.4901
Planting date*spray	4	218.5280000	54.6320000	0.98	0.4416

*Significant

Appendix 3. Appendix Table 3. Analysis of variance of plant height

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	7250.965333	7250.965333	122.61	<.0001**
Spray	4	400.373333	100.093333	1.69	0.1955
Planting date*spray	4	302.181333	75.545333	1.28	0.3155

**Highly significant

Appendix 4. Analysis of variance of Thousand seed weight

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	0.69342403	0.69342403	60.43	<.0001**
Spray	4	0.06181047	0.01545262	1.35	0.2913
Planting date*spray	4	0.02799513	0.00699878	0.61	0.6608

**Highly significant

Appendix 5. Analysis of variance of grain yield

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	7090643.600	7090643.600	175.85	<.0001**
Spray	4	155390.171	38847.543	0.96	0.4514
Planting date*spray	4	233408.311	58352.078	1.45	0.2594

**Highly significant

Appendix 6. Analysis of variance of WPP before spray application

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	10603.20000	10603.20000	99.97	<.0001**
Spray	4	16.53333	4.13333	0.04	0.9968
Planting date*spray	4	95.46667	23.86667	0.23	0.9209

**Highly significant

Appendix 7. Analysis of variance of WPP After first spray application

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	16652.20800	16652.20800	386.68	<.0001**
Spray	4	187.52533	46.88133	1.09	0.3917
Planting date*spray	4	129.58533	32.39633	0.75	0.5694

**Highly significant

Appendix 8. Analysis of variance of WPP After second spray application

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	25172.03333	25172.03333	483.74	<.0001**
Spray	4	1042.03533	260.50883	5.01	0.0069**
Planting date*spray	4	1146.75000	286.68750	5.51	0.0045**

**Highly significant

Appendix 9. Analysis of variance of number of damaged branches

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	6464.484813	6464.484813	19.33	0.0003**
Spray	4	1033.551580	258.387895	0.77	0.5570
Planting date*spray	4	2022.626220	505.656555	1.51	0.2406

**Highly significant

Appendix 10. Analysis of variance of percentage of damaged capsules

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	21.33633333	21.33633333	90.34	<.0001**
Spray	4	2.78200000	0.69550000	2.94	0.0491*
Planting date*spray	4	2.55533333	0.63883333	2.70	0.0633

**Highly significant *Significant

Appendix 11. Analysis of variance of oil content

Source of variation	DF	Type I SS	Mean Square	F Value	Pr > F
Planting date	1	106.4083333	106.4083333	148.47	<.0001**
Spray	4	6.9582867	1.7395717	2.43	0.0856
Planting date*spray	4	1.9565000	0.4891250	0.68	0.6131

**Highly significant

Plate 1. Early and late planted plots of sesame with 10 days difference

Plate 2. Jatropha and Neem aqueous extracts (Left: Jatropha, Right; Neem)

Plate 3. Caterpillar of Sesame webworm on leaf (Left) and on capsule (Right)

Plate 4. Sesame shoots webbed by sesame webworm

Plate 5. Sesame plots early planting (Left) and late planting (Right)

Plate 6. Sesame capsule damaged by sesame webworm