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Infestation Status of Potato Tuber Moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) on Seed Potato around Holetta and Jeldu in Central Highlands of Ethiopia

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Biology (Insect Science)

November, 2015

ADDIS ABABA, ETHIOPIA

ACKNOWLEDGEMENTS

First of all my gratitude goes to the almighty God, who is helping me to finish this research work. I wish to express my most sincere, appreciation and gratitude to my advisor Dr. Emana Getu for his excellent guidance and comments on the thesis work from the beginning up to the end. I would also like to express my sincere thanks to the Ministry of Agriculture for giving me the sponsorship and covering the full tuition fee for this post- graduate study and research work. I also extend my deepest gratitude to Mr Firehiwot Seife, Miss Kidist Mesfin, Miss Aregash Ayane who have helped me during data collection. I would like to extend my thanks to Mr. Elias Sahledingle for his help in commenting my work.

I am grateful to Mr. Ashenafi Bekele, who translated questionnaires from English to Afan oromo. I would like to acknowledge Mr. Tewodros who helped me in computer skill, especially in the SPSS data analysis. I am grateful to farmers and DAs of Welmera, Ejere and Jeldu districts who responded to all questions with patience and provided me the necessary information for my research work. Last but not least, I would like to thank members of my family, particularly my mother (Yeshihareg Assefa), my Father Nega Zegeye my daughter (Mahlet), my brother Ayalew Assefa, my sister Abiot Nega and my husband Solomon Bereded for their support and encouragement during the course of this study.

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APR	Annual Progress Report
CIP	International Potato Improvement Center
CSA	Central Statistical Agency of Ethiopia
DAs	Developmental Agents
DLS	Diffused Light Storage
EIAR	Ethiopia Institute of Agricultural Research
FAOSTAT	Food and Agriculture Organization Statistics
HARC	Holetta Agricultural Research Center
IPM	Integrated Pest Management
MASL	Meter Above Sea Level
PTM	Potato Tuber Moth
SE	Standard Error
SPSS	Statistical Package for the Social Sciences

ABSTRACT

Potato is the world's fourth largest food crop after wheat, rice and maize. In Ethiopia potato is a potential food security and cash crop due to its high productivity and nutritional quality tuber. However, several factors contribute to the low yield of potato. Among the factors *Phthorimaea operculella* (Zeller) is a major pre and post harvest problem of potato in Ethiopia. The current study was conducted to evaluate the infestation status of *P. operculella* on seed potato. A survey was undertaken in west shewa Zone in three potential potato growing districts Welmera, Ejere and Jeldu. Data on the status of *P. operculella* under field and storage conditions were collected through observations and interview. Field observation was made near potato harvesting time, while observation under storage condition was done in the middle and near the next planting season. Fifty four respondents from all the three study districts were randomly selected and interviewed about various aspects of *P. operculella* in relation to seed potato production, seed storage methods & challenges. Data were collected and analyzed using descriptive statistics. From field observation *P. operculella* infestation was recorded at potato harvest on Belete variety (F2, 47 at 0.05= 13.66, P< 0.000). *P. operculella* infestation was significantly different (F5, 47 at 0.05= 5.82, P< 0.000) among the study districts such that infestation was higher at Welmera and Ejere and lower at Jeldu in the middle storage period. There was significant difference *P. operculella* infestation among kebeles (F5, 47 at 0.05= 10.47, P< 0.000) and highest infestation was recorded at Goro, Choke and Eluaga kebeles near the next planting time. *P. operculella* is not an important pest at the study areas under field condition on rain fed potato production but, infestation that existed under field condition on Belete potato varieties. However, *P. operculella* is an economic pest under storage condition at the study sites though the infestation level varies with the type of storage structure and methods. More infestation was recorded in traditional storage methods, while potato tubers stored in DLS was less infested by *p. operculella*. Farmers and Developmental agents have little or no knowledge of *P. operculella* damage symptom and its importance in the potato production. Awareness creation and training should be given to farmers and developmental agents.

Key words: *Phthorimaea operculella*, field survey, storage, potatoes, knowledge gap

1 INTRODUCTION

1.1 Background

Potato (*Solanum tuberosum L.*), a member of the family Solanaceae and the genus Solanum, is one of the most productive and widely grown food crops next to wheat, rice and maize (Golizadeh and Esmaeili, 2012). This crop is grown throughout the world and originated in the high Andes of South America and start to plant lake Titicaca (Mulugeta Gedif and Dessalegn Yigzaw, 2013). However, the crop was introduced to Ethiopia in 1858 by the German botanist known as Shimper (Berga *et al.,* 1992).

Potato is one of the stable food sources in the world, which have high carbohydrate and low fat content made it a better energy source than cereal for human consumption (Dean, 1994). Potato serves as food and income security to farmers, especially during seasonal food shortage or hunger as potato attain physiological maturity earlier than cereal crops (Sanginga *et al*., 2009). In Ethiopia, potato is the most important crop in terms of volume consumption among tubers and root crops (CSA, 2010).

Even though, the average world yield of potato is 17.4 tons per hectare in 2010 and in the same year the average for the United States of America was 44.3 tons per hectare (FAOSTAT, 2010). However, potatoes can be potentially grown in Ethiopia accounts for 70% of the arable land, over 1.28 million tons of potato have been annually produced from approximately 160,000 ha (CSA, 2008/09; Medhin *et al*., 2000). Ethiopia has good climatic and edaphic conditions for high quality potato production, the national average yield is about 9 tons/ha which is much lower than the world average of 17 tons/ha (Endale *et al.,* 2008a; Ferdu *et al.,* 2009).

Despite the presence of conducive environmental factor for potato production in Ethiopia a number of constraints limit the production and productivity particularly under smallholder farmers condition. Among the factors that contribute to low productivity of potato in Ethiopia are inadequate storage, lack of improved varieties (Ayalew Tewodros, 2014a), marketing facilities and biotic constraints such as fungal disease like late blight, early blight, bacterial wilt, and insect pests, such as *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) (Fuglie, K.O. 2007 and Ferdu *et al.,* 2009).

Even though, in most potato growing areas of Ethiopia the crop is attacked by a number of insect pests, the major one is *P. operculella* (Bayeh and Tadesse 1992; Emana and Amanuel, 1992; Rondon *et al.*, 2007 and Bayeh *et al.,* 2008). *P. operculella* is the most economic pest on potato production in Ethiopia, hence yield loss recorded up to 42% and 8.7 % in store and in the field, respectively (Sileshi and Teriessa, 2001; Tekalign Zeleke *et al.,*2015). Similarly, Lagnaoui *et al*. (2000) 100% yield loss due to *P. operculella* when tubers stored at warm condition.

P. operculella is one of the major potato pests worldwide (Rondon *et al*., 2007a). It is a host specific pest of solanaceous crops, high adaptability to daily and seasonal changes, high reproductive potential, resistance to some insecticides and high potential to destroy potatoes in storage (Chumakov and Kuznetsova, 2009; Binyam Tsedaley, 2015). Moawad and Ebadah (2007) reported that *P. operculella* causes serious damage to stored potato through its larval tunneling and feeding, which lead to partial or complete rotting by subsequent infection of fungi and bacteria.

This insect pest causes significant crop losses in almost all tropical and sub-tropical potato production systems in Central & South America, Asia and Africa (Rolot, 2001). It is zero tolerance for the presence of *P. operculella* larvae in the raw processing product because they are classified as foreign material. Thus, the problem is very critical in affecting seed quality and subsequent performance sprouting of the crop in the field (Endale *et al*., 2008b).

P. operculella economic damage occurs at harvesting or prior or during when the tubers are exposed on the soil surface (Lacey *et al*., 2008; Malakar and Tingey 2006). Bayeh and Tadesse (1992) reported that based on sex pheromone trap monitoring at Holetta, the peak months of *P. operculella* field infestations were January, February and June, but such trend was not observed in stored tubers. In Africa, including Ethiopia *P. operculella* infestation increases where seed tubers are stored under a traditional storage method (Roux *et al.,* 1992).

In Ethiopia, potatoes are stored for ware and seed in different traditional potato storage material: underground storage, floor storage, raised beds and sacks. However, potato yield loss in Ethiopia reached 30% to 50% due to improper storage systems and post-harvest handling problems (Ayalew *et al.,* 2014b). Early harvesting, sprinkler irrigation, cleaning field, storage and separation of infested tubers from healthy tubers are good cultural practices, for the management of *P. operculella* under smallholder farmers *(*Raman, K.V. 1980*)*. Moreover, *P. operculella* activities are significantly reduced at temperature below 18^0C (Guenthner *et al.,* 2003).

However, in the study areas potato production and productivity are affected by different biotic and abiotic factors. From the biotic factor damage by *P. operculella* is considered to be among the most important ones, both under field and storage. Around Holetta potato tuber storage also varies among farmers. Farmers adopted Diffused Light Storage/DLS/ from Holetta Research Centre and store their seed potato in it. As construction of DLS requires some amount of money and farmers who do not afford are forced to store their seed potato differently. Some farmers keep potato tubers in the field for an extended period of time until the next cropping season. Others use a dark place in their house and outside the house covering with crop residues (Adane *et al*., 2010).

Though, seed potato stored in DLS are generally not free of *P. operculella* but, less infestation as compare to traditional storage methods (Bayeh, 2004). Information concerning *P. operculella* current status around Holetta and Jeldu in general and the study districts in particular is not sufficient. However, preliminary survey by the author showed that *P. operculella* problem in stored potato tuber is immense calling for research. Both farmers and Developmental agents were not aware of the problem of *P. operculella* on stored potato tuber mainly used for seed purpose. The purpose of the current work is, therefore, to assess the importance, severity, distribution and generally the status of *P. operculella* at Welmera, Ejere and Jeldu district under small holder farmer's field and storage conditions.

1.2 Objectives

1.2.1 General Objective

To evaluate the infestation status of *P. operculella* on seed potato in three districts of West Shewa Zone.

1.2.2 Specific Objectives

- To determine seed potato infestation level by *P. operculella* in farmer field at the time of harvesting, middle of storage period and next planting season.
- To determine farmers' seed potato storage methods versus *P. operculella* infestation.
- To assess farmers and Developmental Agents knowledge on tuber moth infestation on seed tuber both under field & storage condition.

2 LITERATURE REVIEW

2.1 Potato Production

FAO (2008) reported that potato is one of the world most important crop and consumed for more than 8,000 years ago. Potato started widely cultivated and expanding around the world in the 16th century. The crop is introduced to Europe and Asia in the 17th century and in Africa in the 19th century by Spanish from South America and Andes (Pliska, 2008). Nowadays, the annual World potato production is estimated to 300 million tons (FAO, 2008). Among this, Asia and Europe are the major potato producing countries, which cover more than 80% of the world production. Today, China is the biggest potato producer in the world which, covered, about 20% of world production (Pliska, 2008).

Potato had been imported and grown in Africa for many years. According to the report, South Africa, Egypt and Morocco are the highest producers with productivity ranges 24.2 t/ha to 34 t/ha, while Nigeria and Kenya are the least producer with the productivity ranges 3.1 t/ha to 6.7 t/ha. Also in Ethiopia potato productivity in the same year was 7.2 t/ha, which was similar to the least producer countries (FAO, 2008).

In Ethiopia, the main potato production season is from June to September which is called the rainy season. The off-season potato production is mainly at higher elevations from April to August. About 70% of the country's available agricultural land are located at an altitude range of 1800-2500 meter above sea level, which is suitable for seed and ware potato production (FAO, 2008; Emana and Nigussie, 2011). Potatoes are usually grown in Ethiopia in a multi cropping or rotational cropping system which, rotate with cereal and legume crops, followed by potatoes (Medhin *et al.,* 2001).

Potato is grown in most parts of Ethiopia, with the major production regions located in the central, eastern, northwestern and southern which cover approximately 83% of the potato farmers (CSA 2008/2009). In the central highland area the major potato growing Zones are West Shewa and North Shewa.

From West Shewa Ginchi, Jeldu, Galessa and Holetta are one of the major potato producing areas. Potato is produced mainly in the short rainy, season starting from February to May and long rainy, season from June to Septamber. It is major potato growing area in the country, both seed and ware potato and farmers grow about seven local varieties, eight improved varieties and six clones (CSA 2008/2009).

2.1.1 Potato Harvesting

Potato is a short duration vegetable crop as compared to cereals which, can attain in 3-4 months in Ethiopia (Endale *et al.*, 2008b). Deciding appropriate date on harvesting time which cover the most important practices to maintain the quality and quantity of potato tuber yield (Ayalew *et al*, 2014b). To reduce exposure time, harvest mature tubers as soon as possible and avoid leaving the tubes on the soil surface or on overnight. At harvest, tubers do not always show signs of damage, but may harbor eggs and early instars larvae. *P. operculella* where prefer foliage and tubers for egg laying and feeding. When foliage starts to decline, larvae move through stem or drop on the soil and enter the soil through soil cracks to find feed and egg laying on tubers (Rondon *et al.,* 2007a).

Borgel *et al.* (1980) reported that the dates of harvesting vary depending on weather condition, storage facility, type varieties used, and the availability of labor. Moreover, small-scale farmers affected more by unavailability of appropriate storage methods and farmers forced to keep seed tubers in the ground for next planting season (Fuglie, K.O. 2007).

2.1.2 Seed Potato Storage System

In Ethiopia, there are two types of potato storage methods: traditional and improved storage methods (DLS). Farmers use different traditional potato storage methods such as leaving the tubers in the soil un-harvested (postponed harvesting), light place in the house, dark place in the house, raised beds and in sacks (Adane *et al*., 2010). This storage methods are very critical in affecting seed quality and yield loss. Hence potatoes that are leaving or unharvest in the field for any length of time and delay harvesting can act as a source of inoculums for disease and insect pests like *p. operculella* (Borgel *et al*., 1980; Endale *et al.,* 2008a; Rondon, S. I. 2010). A study by Tesfaye *et al.* (2008) in Gojam and Gonder, around 50% of potato yield loss by *P. operculella* when the tubers stored in traditional underground storage. Therefore, farmers due to shortage of storage facilities buy seed tubers at high prices during planting and forced farmers to sell their potato at low prices during harvesting.

However, farmers are aware of the new seed storage technology that is, Diffused Light Store (DLS). Since its introduction in 1988, DLS has been rapidly adopted, as it is very useful and simple to construct with locally available materials. Ethiopia Institute of Agricultural Research tested demonstration models of DLS structures in the community of Welmera, Jeldu, and Degem districts in the central highlands of Ethiopia (Medhin *et al.*, 2001). The advantage of DLS over traditional storage system is that seed potato can be safely stored for 7 to 8 months without seed tuber deterioration (Getachew and Mela, 2000). According to Ayalew Tewodros (2014a) and Agajie *et al.* (2007) report better quality seed tubers are obtained with storage in DLS than in traditional dark storage, which can substitute alternative temperature - controlled storage system.

2.1.3 Potato Varieties and Seed Systems

Over twenty years later Medhin *et al*. (2001) reported that there is no institution in Ethiopia that multiplies and distributes potato seed tubers. Bogel *et al*. (1980) reported that very little imported or certified seed is available to farmers. Thus, farmers are forced to use inferior-sized tubers from different sources such as neighbor farmers, local markets and previous harvests (Almekinders *et al*., 1994). Hence, this practice has contributed to the build-up of diseases and pests, which leads to low yield. According to Kidane-Mariam (1980) and Lemaga (1983) local varieties are not free of insect pests, diseases and viral infection. Lack of available seed can be a major factor in determining whether farmers continue to grow potatoes, or to rely only on cereals (Medhin *et al.,* 2001). In Ethiopia, currently, 29 potato varieties were released officially and the most from the EIAR-CIP breeding program (Mekonen *et al.,* 2011).

2.2 Potato Production Constraints

The most important constraints responsible for the low yield of potato production in Ethiopia include, poor agronomic practices, shortage of good quality seeds, absence of well adapted varieties, in sufficient and high quality seed potatoes, sufficient storage and marketing facilities, problems of diseases and insect pests (APR, 1979/80; Medhin *et al*., 2001).

In Ethiopia different authors identified potato production affected by different insect pests among these: cotton aphids, pepper and potato aphid, green peach aphid, death's head halok moth, cutworms, red ants, potato epilachna, Teff epilachna, Metallic leaf beetle and potato tuber moth (Bayeh and Tadesse 1992; Emana, and Amanuel, 1992; Bayeh *et al.,* 2008), but in Ethiopia *P. operculella* and red ant merit close attention. In Ethiopia, *P. operculella* was recognized as important pests in the warmer areas where potato is grown, but now a day's *P. operculella* has been an important pest in high land in major potato growing areas.

Alvarez *et al.* (2005) stated that the damage caused by *P. operculella* is a very severe case of significant economic loss of potato ranging from 50% to 100% under potato storage in the world. Adhanaom *et al*. (1985) reported that, *P. operculella* is the most damaging pest of potato in Ethiopia, where the damage due to this pest could reach up to 91%. It is distributed to other places at the time of seed tuber transportation from one place to another (Bayeh *et al*., 2008; Tekalign Zeleke *et al.,* 2015).

2.3 *P. operculella*

2.3.1 Status of *P. operculella*

P. operculella in the first time reported in California in 1856 but, now a day distributed in the United States at least 25 states from the Atlantic to the Pacific coast (Alvarez *et al.*, 2005). *P. operculella* was described in 1873 as *Gelechia operculella* (Zeller, 1873), hence, the genus was revised in 1902 and 1931 and assigned to the genus *Phthorimaea* (Meyrick, 1902). Golizadeh and Esmaeili (2012) reported that, *P. operculella* a cosmopolitan pest in sub- tropical and tropical countries and it is responsible for very important losses in potato production. Now a day *P. operculella* widely distributed all over the world, in Africa Asia, Europe, the America, and Oceania (Ahmed *et al.*, 2013; Kroschel *et al.,* 2013).

2.3.2 Host Range of *P. operculella*

P. operculella also known as potato tuber moth or tobacco split worm. It is an oligophagous pest of crops, feeding on the Solanaceae family only. *P.operculella* larvae are primarily feeding on potatoes, followed to other plants such as tomatoes, tobacco, eggplants, peppers and wild solanaceous plants or Datura (Alvarez *et al.*, 2005; Chumakov and Kuznetsova, 2009). Currently *P. operculella* is mostly a serious pests on tobacco production (Rondon *et al.,* 2007; Golizadeh and Esmaeili, 2012).

2.3.3 Damage Symptoms of *P. operculella* on Potato

P. operculella is one of the serious pests on the potato production in the worldwide (Rondon *et al.,* 2007a) and it is both a pre and post harvest problem. *P. operculella* larvae may cause economic losses in potato production into two ways: first, when farmers observe *P. operculella* infestation in his field, he may forced to sell his product prematurely in low price. Second, it's reduced both seed and ware quality which lead to low market price. The larvae feed and create mining on potato leaves, stems, petioles, and tubers in the field and in the store. As a result, the newly hatched larvae eating the leaf tissue without damaging the epidermis (Rondon *et al.*, 2007b; Gill *et al.,* 2014). Hence, infested plants can be known by larvae make mines symptom in the leaves, stems and webbing together of adjacent leaves (Chumakov and Kuznetsova, 2009).

Rapidly moving larvae penetrate the tubers, form galleries coated with silken threads. Larval excrement is pushed out and eject frass through the holes, which can be noted immediately after larvae start mining activity (Rondon *et al.,* 2007b). The larvae tunnel deep into the flesh creating dirty looking or black tubers filled with larval excrement (Rondon *et al.,* 2007a). Therefore, the presence of even one larva is enough to spoil and destroy a tuber which can release an bad odor and rendering them unmarketable and unfit for human consumption or seed purpose (Palacios *et al*., 1998; Guenthner *et al*., 2003). The P. operculella feeding and damage symptom shown in Plate 1.

PLATE 1: Black tunnels and feeding damage of *P. operculella*. Source: (Rondon, S. I. *et al.,* 2007).

2.3.4 Life Cycle and Ecology of *P. operculella*

P. operculella a complete metamorphosis pest and has four life stages: adult, egg, larva and pupa. Adults *P. operculella* have silvery-gray in color, have a narrow body, and are approximately 10 mm in length. Forewings have dark spots, with folded external edge and a fringe longer than it is wide. The forewings have dark spots as shown “X” pattern for females and 2-3 dots on males and both pairs of wings have fringed edges Plate 2 (Rondon *et al.,* 2007a; University of Nebraska–Lincoln, 2015). It is mostly active during the night such as mating and oviposition and poor fliers behavior (Talekar, 1998; University of Nebraska–Lincoln, 2015).

PLATE 2: *P. operculella* female (left) “X” pattern and male (right).

Source: (Rondon, S. I. *et al*., 2007).

P. operculella females begin laying eggs 2 days after emerging from their cocoons and can live 30 days. Laying eggs prefer on the lower sides of plant leaves and sometimes on leaf stalks, stems, exposed potato tubers, lumps of soil in the field, on potato tubers at the buds and on bags in store houses (Rondon *et al*., 2007a; Chumakov and Kuznetsova, 2009).

P. operculella female can crawl through soil cracks or burrow short distances through loose soil to find tubers on which to deposit eggs (Rondon *et al.,* 2007a). Female fecundity is 150-200 eggs, with 165 on average (Chumakov and Kuznetsova, 2009). Once the eggs hatch, the larvae feed on the foliage or tubers depending on where the eggs were deposited. The larvae mature in 16 to 24 days (Alvarez *et al.,* 2005) or 11-14 days (Chumakov and Kuznetsova, 2009; University of Nebraska–Lincoln, 2015), while larvae pass through 4 instars, the pupal stage lasts 6 to 9 days.

Egg: is smooth, oval, translucent, and range in color from white or yellowish to light brown (Plate. 3), about 0.4-0.6 mm in length and 0.4 mm in width. Freshly laid eggs are white and turn to yellowish to brown and finally turn black just prior to hatching (University of Nebraska–Lincoln, 2015; Rondon *et al*., 2007a).

Larva: is white or yellow with a brown head and mature or older larva color changes from white or yellow to pink (Rondon *et al.,* 2007a; Chumakov and Kuznetsova, 2009). Larvae feed on leaves throughout the canopy, but prefer the upper foliage. Plate 3 *P. operculella* larvae form tunnels under the epidermis of leaves and stalks. One larva makes 3 - 4 tunnels, gradually filling them with excrement and create twisting tunnels in tubers (Chumakov and Kuznetsova, 2009).

Pupa: is smooth and brown and are often enclosed in a covering of fine sediment. About 5.5-6.5 mm in length and it develops in a silky cocoon of grayish silvery color that reaches 10 mm in length (Chumakov and Kuznetsova, 2009).

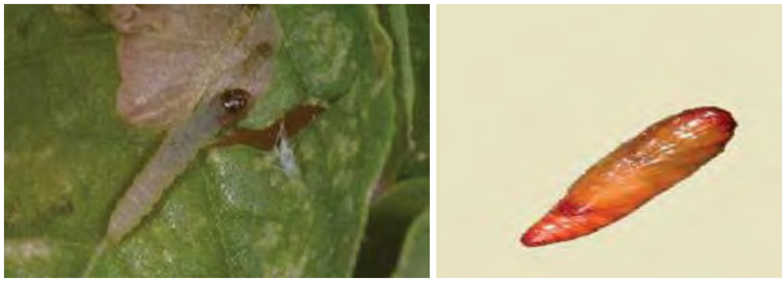

PLATE 3: *P. operculella* the epidermis *P. operculella* pupa (right)

(Tunnels under the epidermis (left) Source: (Rondon *et al*., 2007a)

Larvae close to a population drop from the infested foliage to the ground and may burrow into the tuber to complete its life cycle. Moreover, pupation occurs inside hidden cocoons located in various shelters such as under dust, on bags/sacks, in floor cracks (Chumakov and Kuznetsova, 2009). Rarely *P. operculella* pupae can be found on the surface of the tubers, most commonly associated with indentations on the tuber eyes, but usually are not found in the tubers (Rondon *et al*., 2007).

P. operculella has adapted to a large climatic range, although its biological activity increases with temperature. The potato moth develops 3-4 generations in the Krasnodar and 4-5 generations in Southern Ukraine while in warmer temperatures *P. operculella* complete their development within 5 weeks in New Zeland (Alvarez *et al.,* 2005). The life cycle complete in short period in summer ranging from egg to adult 22-30 days and long in winter to 2-4 months. The optimum temperature requires for moth development is ranging from 22-26°C and the air humidity levels of 70-80% (Chumakov and Kuznetsova 2009).

However, considering temperature factors Pucci *et al*. (2003) indicated that if the ambient temperature is at 25°C or higher, they will stop ovipositing. *P. operculella* does not normally enter diapauses in ontogenesis. This allows it to continuously reproduce and has overlapping generations when, suitable temperature and food is available such as potato tubers in seed or ware potatoes storehouses (Sporleder, 2007; Chumakov and Kuznetsova 2009).

2.4 *P. operculella* Management

2.4.1 Cultural Control

Cultural control is a good practice for the support and reduce *P. operculella* damage to potato tubers and improve the yield and quality of potato (Hanafi, 1998). Weeds and any volunteer plants can act as alternate hosts for *P. operculella*, and should be eliminated from fields and surrounding areas (Rondon *et al.*, 2007; Gill *et al.,* 2014). Moth populations are maintained in plant and tuber debris in the field in the absence of the main crop. Therefore, timely field cleanliness and discard infested tuber seeds are an important preventive measure. Alvarez *et al. (*2005) and Chumakov and Kuznetsova (2009) outlined healthy seed tubers planting and good coverage of potato seeds with soil 1 to 2 inches of which, significantly reduces tuber infestation by *P. operculella*. Cull piles should be destroyed to reduce overwintering stages of *P. operculella*. After harvesting tubers soon transported overnight in the field as to prevent these potatoes could act as egg laying for *P. operculella* (Raman, 1980; Alvarez *et al.,* 2005; Rondon *et al*., 2007; Anonymous, 2013).

Continuous cropping of host plants increases infestation levels, which provide more favorable conditions for the reproduction of *P. operculella* linked with that particular host. Therefore, crop rotation helps to reduce and disturb the population build up of *P. operculella* in the field and preventing it from attacking the following year's crop (Baldwin Keith R. 2006; Adane *et al.,* 2010). The rotation of crops has proved to be the most cultural control measure against those pests which are mono phagous or restricted feeders, slow breeder and having a longer duration of feeding phase (Shukla, G. S and Upadhyay,V.B. 2007).

2.4.2 Soil Management

The recommended planting depth is one of the main agronomic practices required for potato production which, reduced seed exposed to light. Proper irrigation is the most successful preventative method under dry conditions to avoid soil cracking (Raman, 1980). Cracking of the soil higher in furrow-irrigated fields which is more severe to infest by *P. operculella* than sprinkler irrigation (Kroschel, 2003). Irrigated after vine desiccation to avoid soil cracks and that the harvest of tubers occurs as soon as the skin sets (Anonymous, 2013). Prevention of soil cracking in the beds will reduce *P. operculella* entering the soil and reduced soil oxygen due to water saturation, which reduced their mobility and ability to find a tuber (Rondon *et al.*, 2007).

2.4.3 Host Resistance

The use of resistant varieties are a key component of an integrated pest management (IPM) program for *P. operculella*. Varietal selection and using natural host plant resistance is the first line of defense in the control of *P. operculella* damage (Lagnaoui *et al.*, 2000). The cultivation of resistant varieties could reduce the chemical application and increases the effectiveness of alternative control methods (Golizadeh and Esmaeili, 2012). Varietal differences in susceptibility to *P. operculella* damage may be due to differential feeding by larvae or to adult egg - laying preferences. According to (Rondon *et al.*, 2007), planting potato in shallow depth setting results more susceptible than varieties that set tubers deep against *P. operculella* infestation in the field.

2.4.4 Storage Management

P. operculella is a year round problem under storage conditions due to continuous reproduction favoured by suitable environmental condition and food availability (Sporleder, 2007; Pucci *et al.*, 2003). Hence, the length of the life cycle of *P. operculella* is highly dependent on temperature and high accumulation of tubers on the shelf (Bayeh, 2004). Therefore, frequent monitoring stores of potatoes is importance by using pheromone traps based on signs of rot and insect damage. This storage observation helps to prevent the spread and development of *P. operculella* and to decide control options. Cultural control under storage is the most important option involve removal of damaged tubers and sanitation of storage facility walls, floors, and ceiling (Gill *et al.*, 2014). In addition to this, treat tubers and facility with recommended chemicals, if this pest was detected in the previous year. However, pyrethroids chemicals are good for potatoes stored for seed purpose but, Bt spray can be used on tubers which are mainly used for human consumption (Anonymous, 2013).

2.4.5 Chemical Control Methods

The base line of pest management should be based on field-specific information. *P. operculella* populations vary greatly from field to field as well as area to area. Therefore, crop field should be monitored regularly by using through pheromone traps to determine *P. operculella* populations and helps to know time of insecticide applications (Herman *et al.,* 2005).

P. operculella control in potato stores practiced by applying dust chemicals on the potatoes with malathion or carbaryl powder (Kroschel, 2003). In Ethiopia the systhemic insecticide diazionon 60% EC used effectively to control *P. operculella* in the field and storage (Ferdu *et al*., 2009). Rondon *et al*. (2007a) and Gill *et al.* (2014) recommended the exact insecticide application on *P. operculella* to reduced yield damage of potato when the moth catch of pheromone traps exceeds 15-20 adults per trap each night. *P. operculella* can be controlled by insecticides, but the treated potato tubers in contact with systhemc insecticides, can be used only as seed because of the health hazard from residues if used in ware (Lal, 1987).

2.4.6 Integrated Pest Management (IPM)

Integrated Pest Management is a broad-based approach that integrates a range of practices for economic control of pests with, least possible hazard and environmentally sound. Before applying IPM program comprehensive information on the life cycles of pests, ecology and plant pest interaction required (Dolucchi, 1987; Binyam Tsedaley, 2015). It uses all suitable pest control techniques in a compatible manner to reduce pest populations below economic injury levels. In IPM a variety of complementary pest control measures: cultural practice, host resistance varieties, biological control, botanical and the last option chemical control which should be both economic control and environmentally sound (Fuglie *et al.,* 1991). IPM in potatoes is similar to that of other crops and there are beneficial species used for biological control that occur in potato crops worldwide. Cultural control and selective pesticide applications (Horne & Page, 2009) are very important in IPM program for *P. operculella* management.

3 MATERIALS AND METHODS

3.1 Description of the Study Areas

Surveys on the status of *P. operculella* infestations were conducted in the major potato producing districts of West Shewa Zone, Ethiopia, namely Welmera (Goro and Choke Kebeles), Ejere (Eluaga and Beso Kebeles) and Jeldu (Chilako and Edensagelan Kebeles) (Plate 4). The districts were purposively selected as they are potentially better than other districts in terms of seed potato production and storage.

3.1.1 Welmera and Ejere Districts

Welmera and Ejere are located in western Shewa Zone of romia 30 km and 41km west of Addis Ababa respectively, at 9^0 11' 57.5"N and 38^0 24' 34.8"E and at an elevation ranging from 2,060 - 3,380 m.a.s.l. The districts are characterized with the average maximum and minimum temperatures are 24 °C and 6 °C, respectively, and average relative humidity of 60.6% (Zelalem *et al*., 2007). The area receives an annual rainfall of above 1,100 mm. The general soil types of the districts are nito soil & Vertis soil (Chilot, 1993). The climate is characterized by bimodal rainfall consisting of a long rainy season (June- September), short rainy season (February - April) and a dry season (October - January. Farmers rotate cereals with legumes and potato at two to three year intervals.

3.1.2 Jeldu District

Jeldu district is located in West Shewa Zone of Oromia regional state, 115 km west of Addis Ababa at 9^0 15' 54.9" N and 38^0 04' 54.4" E and at an elevation ranging from 2,500 -3,200 m.a.s.l. The district is characterized with the average maximum and minimum temperatures of 16.9°C and 2.1°C, respectively, with average annual rainfall of 1,200 mm and relative humidity of 60.6% (Getachew *et al*., 2014). The general soil types of the district are vertis soil. It has a bi-modal rainfall pattern whereby it receives the short rain between March and April which helps land preparation, potato planting, planting of maize and sorghum. The long rainy season starts from mid May and continues up to mid

September. The types of crops grown are potato, barley, wheat, faba bean, pea, teff, sorghum, maize and oil seeds. Farmers are using crop rotation pattern for the purpose of increasing soil fertility and crop productivity (Kebebe *et al.,* 2010).

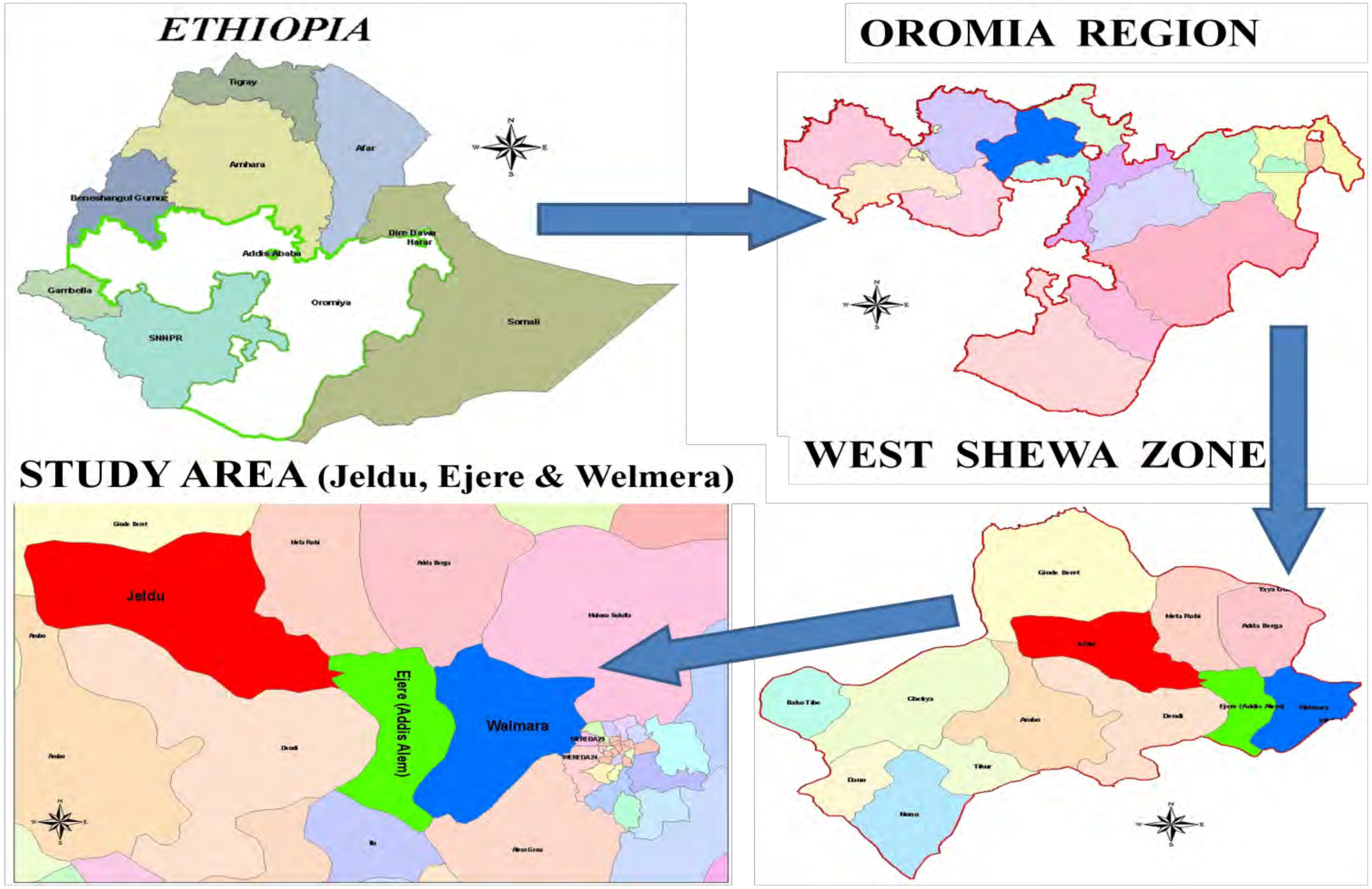

PLATE 4: Map of the experimental sites, Welmera, Ejere and Jeldu: Source (Ethiopia Mapping Agency, 2000)

3.2 Sampling Procedures and Data Collection

The studies were conducted during the main season planted seed potato in 2014 in May to June and data collected in mid September at field, January and April at storage. The surveys were conducted in the three districts Welmera, Ejere and Jeldu, which can represent the highland potato production areas of the country. Within the district, two administrative Kebeles were selected based on their seed potato production potential and storage. From these kebeles, a total of 48 farm households (8 from each kebele) were selected randomly. Data on the infestation level of *P. operculella* under field and storage conditions were collected through observations and interview with farmers and DAs. Field observations were made at potato harvesting, after mid storage in January and at the time of next planting season in April. Fifty four respondents consisting of six Development Agents /DAs/ and 48 farmers were randomly selected from all the study areas and interviewed. Data were collected using semi-structured questionnaire (Annex 12) to know about the current *P. operculella* infestation on seed potato in selected areas in relation to seed potato production, seed storage methods and challenges they face in potato production.

Field Study

Thirty tubers from the center and four margins of each study, which is the total of 150 tubers were randomly sampled at harvest and mixed up for *P. operculella* evaluation. Then the mixed tubers were sorted out as infested tubers and un infested tubers. Then the infested tubers were evaluated interms of number of terminated galleries per tuber, number of active galleries per tuber, number of larvae and pupae per tuber

Storage Study

A few number of tubers were randomly picked from each shelf of the diffused light storage to get a total of 300 tubers from each store. In the case of traditional stores a total of 300 tubers were randomly sampled from the top, middle and bottom of the storage structure. The 300 tubers collected from each store using an incremental sampling technique were thoroughly mixed up and 150 tubers were randomly sampled and evaluated for *P. operculella* infestation using the same parameters as the field study.

3.3 Data Analysis

Field collected data and semi-structured interviews were summarized using descriptive statistics such as mean, frequencies, and percentage with Statistical Package for the Social Sciences (SPSS) version 16.0. Moreover, the mean number of infested tubers, the mean number of terminated galleries/tuber, active galleries/tuber, number of larvae/ tuber and number of pupae/ tuber were computed and analyzed using one way ANOVA. Significant means were separated using Tukey's studentzed range test at 5% significant level.

4 RESULTS AND DISCUSSIONS

4.1 *P. operculella* Infestation Levels at Harvest

Mean number of *P. operculella* infested tubers at harvest is shown in Table 1. According to the table significant difference at (F5, 47 at 0.05= 9.14, P< 0.0001) was observed among the kebeles. The highest mean number of *P. operculella* was recorded at Goro kebele, while the other kebeles were not statistically different (Table 1).

TABLE 1: Mean number of infested tubers by *P. operculella* per kebele at the time of seed potato harvest.

Kebeles	Mean number of infested tubers*
Goro	8.25 ± 2.35 a
Choke	3.13 ± 1.17 b
Beso	0.25 ± 0.16 b
Chilako	0.25 ± 0.25 b
Edensagelan	0.13 ± 0.13 b
Enluaga	0.13 ± 0.13 b
F- value	9.14
P- value	<0.0001

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

Mean number of active galleries and mean number of larvae per tubers is shown in (Table 2). Goro and Choke kebeles significantly had the highest active galleries (F5, 47 at 0.05= 6.52, P< 0.0001) and number of larvae (F5, 47 at 0.05= 4.43, P< 0.0001). There was no number of larvae recorded from Beso, Edensagelan, Chilako and Eluaga kebeles even if the tubers were infested.

TABLE 2: Mean number of active galleries and number of *P. operculella* larvae per/ tubers at the time of seed potato harvested.

Kebeles	**Active galleries/tubers***	**Number of larvae /tubers***
Goro	1.08 ± 0.255a	0.53 ± 0.22 a
Choke	1.06 ± 0.257 a	0.21 ± 0.11 a
Beso	0.25 ± 0.16 b	0.00 ± 0.00 b
Edensagelan	0.13 ± 0.13 b	0.00 ± 0.00 b
Chilako	0.13 ± 0.13b	0.00 ± 0.00 b
Eluaga	0.13 ± 0.13b	0.00 ± 0.00 b
F- value	6.52	4.43
P- value	<0.0001	<0.0001

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

Mean number of infested potato varieties in the study areas at potato harvesting is shown in (Table 3). There was significant difference betwen potato variety ($F_{2, 47}$ at 0.05= 13.66, P< 0.000). The highest *P. operculella* infestation was recored on Belete variety at potato harvesting than Gudene and Jalene potato varieties.

TABLE 3: Mean number of infested potato varieties by *P. operculella* in the study areas at the time of seed potato harvest.

Types of potato varieties	**Mean number of infested variety/study areas***
Belete	7.62 ± 2.53 a
Gudene	0.91 ± 0.35 b
Jalene	0.20 ± 0.20 b
F- value	13.66
P- value	<0.000

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

From the observation made *P. operculella* infestation on potato tubers were not economically important for most of the kebeles surveyed on the main season planted seed tubers. There was infestation observed in Goro and Choke kebele at harvest due to the fact that farmers use a susceptible variety known as Belete (Table 3). This variety is more susceptible may be due to its big seed size. This result agrees with Lacey *et al*. (2008) who reported that *P. operculella* economic damage occurs towards the end of the growing season when tubers were exposed. The majority of the farmers were growing Gudene potato variety which have small tuber sizes (Table 12) and less infestation as compared to Belete variety. Farmers also practice earning-up which, create barriers to *P. operculella* to come in contact with the tubers. Alvarez *et al. (*2005), Chumakov and Kuznetsova (2009) reported that hilling of potato with 2 inch thick soil significantly reduces potato tuber damage by *P. opercullela*. Rondon *et al.* (2007) reported that shallow setting varieties are generally more susceptible to *P. operculella* than varieties that set tubers deeper in the ground.

The field observation in the study areas indicated low potato tuber damage by *P. operculella* this could be due to continuous rainfall up to mid October, which minimized soil cracking and prevent larvae entry to the ground for damage tubers. Potato grew in the main season in the study areas faces a low temperature which, delay developmental period of *P. operculella* that has a negative impact on *P. opercullela* density. Bayeh and Tadesse, (1992) reported that in Welmera and Jeldu the peak period for *P.opercullela* were January, February, and June in the field.

4.2 *P. operculella* Infestation Levels in the Middle of Seed Potato Storage in January

The mean number of infested tubers by *P. operculella* is shown in (Table 4). There was significant difference between kebeles at ($F_{5, 47}$ at 0.05= 5.82, P< 0.000). The highest mean number of infested tubers were recored at Goro, Choke and Eluaga kebeles while, Beso, Edensagelan and Chilako had the lowest mean number of infested tubers.

TABLE 4: Mean number of infested tubers by *P. operculella* per kebele at middle seed potato storage period in January.

Kebeles	Mean number of infested tubers*
Goro	31.25 ± 11.37 a
Choke	20.50 ± 3.95 a
Eluaga	18.00 ± 2.93 a
Beso	3.87 ± 2.10 b
Edensagelan	1.87 ± 1.31 b
Chilako	0.50 ± 0.50 b
F- value	5.82
P- value	<0.000

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

Table 5 demonstrated that Goro, Choke and Eluaga kebeles are significantly different at (F5, 47 at 0.05= 9.69, P< 0.000) had the highest mean number of active galleries and *P. operculella* larvae (F5, 47 at 0.05= 7.11, P< 0.000). The rest Beso, Edensagelan and Chilako kebeles had no larvae recorded from the infested tubers.

TABLE 5: Mean number of active galleries and number of *P. operculella* larvae per tubers at middle seed potato storage period in January.

Kebeles	Active galleries/tubers*	Number of larvae/ tubers*
Goro	1.67 ± 0.35 a	0.21 ± 0.06a
Choke	1.36 ± 0.08 a	0.25 ± 0.07a
Eluaga	1.19 ± 0.06 a	0.19 ± 0.05a
Beso	0.44 ± 0.21 b	0.00 ± 0.00b
Edensagelan	0.33 ± 0.22 b	0.00 ± 0.00b
Chilako	0.12 ± 0.12 b	0.00 ± 0.00b
F- value	9.69	7.11
P- value	<0.000	<0.000

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

Mean number of *P. operculella* infestation per store at middle seed potato stored is shown in (Table 6). According to the table significant difference (F3, 47 at 0.05= 10.14, P< 0.000) was observed among the stores. The highest mean number of infested tubers per store were recorded seed tubers stored in traditional storage methods (out sids the house and dark place the in the house), while leat recorded in DLS storage type.

TABLE 6: Mean number of infested tubers by *P. operculella* in traditional storage methods and DLS at middle seed potato storage period in January.

Types of storage methods	**Mean number of infested tubers per /stores***
Outside the house	35.20 ± 15.18 a
Dark place in the house	29.75 ± 3.47 a
In the field not harvested	23.33 ± 9.78 a
DLS	5.24 ± 1.13 b
F- value	10.14
P- value	<0.000

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

P. operculella levels of infestation measured in the survey were substantially higher than those found in an earlier field survey. From the field study made *P. operculella* infestation on seed potato stores were economically important in Welmera (Goro and Choke) and Ejere (Eluaga) districts. This is the reason for concern since the factors affecting seed tuber damage by *P. operculella* was storage method and seed quality.

In the study areas, farmers used two type of seed potato storage methods: traditional and improved storage (DLS) methods. *P. operculella* infestation level increased with those farmers who stored their seed potato in traditional storage methods like a dark place in the house and outside the house covering with crop straw (Table 6). Based on different review reports in Africa, including Ethiopia the highest *P. operculella* infestation were observed where seed tubers are stored under a traditional storage methods (Roux *et al.*, 1992). Moreover, these traditional storages are not able to store for long period without insect pests or disease damage, bulk storage and reduced the farmers housing safety for those who store in the house (Ayalew *et al*., 2014b). According to (Agajie *et al.,* 2007) report better quality seed tubers is obtained with storage in DLS than in traditional dark storage.

Due to economical capacity and lack of awareness about DLS, farmers are forced to store their products in traditional storage methods. Medhin *et al.* (2001) recommended that DLS adoption in the central highlands of Ethiopia, was very useful and simple to construct with locally available materials. Diffused Light Storage cannot totally protect *P. operculella* damage, but keep the infestation to low level compared to traditional storage methods (Table 6). From field observation the major source of infestation often comes DLS constructed with South to North direction, from the field and infested tubers left in the stores. One possible reason for this might be the storage structure constructed East to West direction the tubers not much exposed to light which, reduced the room temperature. Moreover, tuber moth infestation was increased at stores as of *P. operculella* larvae and eggs could be transported from field to storage (Bayeh, 2004; Hanafi, A. 1999) and high accumulation of seed tubers on the shelf in DLS Annex 10.

However, the majority of farmers in Jeldu have used DLS methods, those constructed in East to Weast direction and less conducive for *P. operculella* growth and development. Based on respondent interviewed result, most farmers get seed tubers from own storage and research centers (Table 13). These seed sources might be reduce *P. operculella* infestation as compared to neighbor and market. However, in Welmera *P. operculella* infestation increased due to seed source and seed potato production has a longer history (Bayeh, 2004).

4.3 *P. operculella* Infestation Levels on Stored Potato Tubers at the Time of Next Planting Season

Status of *P. operculella* on potato tubers stored up to the next cropping season in terms of mean number of infested tubers, mean number of active galleries and mean number of *P. operculella* larvae per tubers is shown in Tables 7 and 8. The highest mean number of infested tubers by *P. operculella* was recorded in Goro kebele ($F_{5, 47}$ at 0.05= 10.49, P< 0.000) while the lowest was recorded in Chilanko kebele (Table 7). The highest mean number of active galleries and larvae/tubers are recorded at Goro kebeles, while the lowest for both parameters were recorded at Chilako kebele (Table 8). The mean number of terminated galleries and number of pupa per tubers was counting on more infested tubers in storage at next planting time (Table 9).

TABLE 7 : Mean number of infested tubers by *P. operculella* per kebele in seed potato stored for next planting season in April.

Kebeles	Mean number of infested tubers*
Goro	46.25 ± 5.63 a
Choke	33.62 ± 10.53 a
Eluaga	24.62 ± 5.21 a
Beso	9.25 ± 0.95 b
Edensagelan	4.12 ± 3.71 b
Chilako	1.12 ± 0.78 c
F- value	10.49
P- value	<0.000

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

TABLE 8: Mean number of active galleries and number of *P. operculella* larvae per tubers in seed potato stored for next planting season in April.

Kebeles	Active galleries/ tubers*	Number of larvae/ tubers*
Goro	2.04 ± 0.19a	0.52 ± 0.16a
Choke	1.84 ± 0.18 a	0.35 ± 0.01 a
Eluaga	1.30 ± 0.08 ab	0.30 ± 0.02a
Beso	1.13 ± 0.09 ab	0.21 ± 0.02 ab
Edensagelan	0.16 ± 0.16 c	0.02 ± 0.02c
Chilako	0.00 ± 0.00 c	0.00 ± 0.00c
F- value	36.56	7.91
P- value	<0.000	<0.000

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized range test (HSD).

TABLE 9: Mean number of terminated galleries and number of *P. operculella* pupae per tubers in seed potato stored for next planting season in April.

Kebeles	Terminated galleries /tubers*	Number of pupae/ tubers*
Choke	0.11 ± 0.03 a	0.07 ± 0.02a
Goro	0.07 ± 0.03a	0.06 ± 0.01a
Eluaga	0.07 ± 0.01a	0.03 ± 0.01a
Beso	0.00 ± 0.00b	0.00 ± 0.00b
Edensagelan	0.00 ± 0.00b	0.00 ± 0.00b
Chilako	0.00 ± 0.00b	0.00 ± 0.00b
F- value	4.12	3.83
P- value	<0.004	<0.006

* Means ± SE followed by the same column with different letters (s) are significantly different at 5% using a Tukey Studntized Range Test.

The survey result showed that the highest *P. operculella* infestation was recorded in samples collected from the two districts Welmera and Ejere compare to Jeldu ($F5, 47$ at $0.05= 10.49$, $P< 0.000$). These field observation results indicated that *P. operculella* infestation increased under storage condition, particularly when the storage period was extended. Storage structure as well as storage sanitation is the major factors in increasing *P. operculella* damage on seed tubers. *P. operculella* damage increased in store tubers, when the farmers stores their products in traditional storage methods and inappropriatly constructed DLS. *P. operculella* infestation was low in Jeldu, due to the fact that the majority of the farmers stores their products in the improved or in DLS storage methods (Table 13).

4.4 Interviewed Farmers Categorization and their Perception about *P. operculella* Damage on Seed Potato

Farmers questionnaires results are grouped into different age groups, education background and potato land holding (Table 10). According to (Table 10), 43.8 % of the respondent were individuals from a middle age group, about 54.2% of the respondents are primary school and about 62.5 % of the respondents grow potato on 0.25-1 ha of land.

TABLE 10: Comparative socioeconomic characteristics of the respondents (n=48)

Characteristics		**No of respondents**	**Percentage %**
Age	Younger farmers (18-29)	19	39.6
	Middle age (30-50)	21	43.8
	Elderly (> 50)	8	16.7
Literacy status	Illiterate	6	12.5
	Primary school	26	54.2
	Junior secondary school	12	25
	Senior secondary school	4	8.3
Total potato planted area in ha	0.25-1ha	30	62.5
	1.5-3ha	12	25.0
	3.5- 6 ha	3	6.2
	6.5-9 ha	3	6.2

The farmers and DAs general knowledge about *P. operculella* occurrence in the field and storage shown in (Table 11). More than half percent of the respondents had knowledge gap on identification of *P. operculella* larva and its damage potential in potato production. Around thirty respondents had information on *P. operculella* occurrence in the field starting from October up to April while, the least number of the respondents have a lack of awareness on *P. operculella* occurrence at the store. Majority of the respondents (68%) have lack of information on the damage stage of *P. operculella.* Even though, almost all farmers (97%) or the respondents agree as *P. operculella* cause severe damage on the potato production when harvesting delayed.

TABLE 11: Respondents' knowledge on *P. operculella* occurrence & damage potential in field & storage (n=54)

Respondents' interview result	**Frequency**	**Percent %**
The respondents' knowledge		
The respondent knowledge on *P. operculella* damage potential on seed potatoes		
Yes	24	44.4
No	30	55.5
The respondent knowledge on month of *P. operculella* occurrence on potato field		
End of September	4	7.4
October - April	30	55.5
None	20	37.03
The respondent awareness on *P. operculella* occurrence in seed potato stores		
Yes	18	33.3
No	36	66.6
The respondent information on damage stage of *P. operculella* & larva from others		
Yes	17	31.48
No	37	68.51
P. operculella causes severe damage to the seed potato production		
Agree	53	97.9
Disagree	1	2.1
Suggestion concerning potato production in the study area		
High change	28	51.85
Medium change	18	33.3
No change	8	14.81

n= number of respondents

From field observation, female farmers equally participate with male, and no gender difference was noted in terms of task assignments for all six sites. Duties and responsibilities of women also took part in all activities done by men such as planting, hilling up, organic fertilizer application, weeding and harvesting. This work division and field participation is good for insect pest observation . Twelve percent of the respondents had no formal education, thus farmers need to get basic education. However, better educational status has ability to easily understand and interpret the information transferred to them from Development Agents (Getahun *et al.,* 2000).

The first line of pest management is knowing the pest status. During the survey, both farmers and development agents have knowledge gap on *P. operculella* economical damage on potato production under storage condition. However, the majority of respondents information shows as *P. operculella* occurrence peak months in the field starting October to April. This interview results agree with Bayeh and Tadesse (1992) reported that the peak months of *P. operculella* field infestations were January, February, and June, such trend was observed by farmers. Both farmers and developmental agents not able to identify the *P. operculella* larvae mine on foliage and tubers. Finally, after observation and discussion farmers agree that *P. operculella* cause severe damage on the potato production. At present majority of the farmers, especially in Jeldu changed their life through potato production, while among the interviewee small number of farmers life not changed on potato production due to lack of information and communication to find good market.

4.4.1 Seed Potato Production System in the Study Areas

Potato production system in the study areas based on crop rotation, use of potato varieties, potato cropping pattern in a year, planting and harvesting dates are shown in (Table 12). According to the table highest proportions of the respondents depict that potato are frequently rotated with barley immediately after the harvest of potato. However, after two years the land is re-occupied by potato. Gudene is the most frequently grown potato variety in the study area. Most farmers plant potato between May 10 and June 30 and harvest starting October.

TABLE 12: Potato production system in the study area (n=48)

Cropping pattern	**Types of crop & cropping dates**	**Frequency**	**Percent %**
Crop rotation before one year	Barley	32	**66.7**
	Wheat	7	14.6
	Beans	1	2.1
	Teff	7	14.6
	Non crop land	1	2.1
Crop rotation before two years	Barley	8	16.7
	Wheat	11	22.9
	Beans	3	6.2
	Potato	14	**29.2**
	Teff	2	4.2
	Non crop land	10	20.8
Potato varieties grown currently	Gudene	35	**72.85**
	Belete	8	16.67
	Jalene	5	10.48
Potato cropping pattern in a year	One cropping season	14	29.2
	Two cropping season	34	**70.8**
Potato planting dates	May 10 - May 30	14	29.2
	May 10 - June 30	25	52.1
	June10 - June 20	9	18.8
	Sep.15 - Sep.30	4	8.3
	Oc.1 - Oc.30	23	**47.9**
	Oc. 1 - Nov. 30	17	35.4
	Oc. 1 - Jau.30	1	2.1
	Oc.1 - March 30	3	6.2

This survey result indicated that majority of farmers practice crop rotation system for potato planting (Medhin *et al.*, 2001). Hence, potato rotates with cereal and legume in a period of two years, which helps to increase soil fertility and reduced different insect pest attacks in the soil. The interviewed result confirms the finding by Adane *et al.* (2010) and Baldwin, (2006) who stated that crop rotation reduces insect pests.

More than half percent of the respondents dominantly grow Gudene, thus varieties due to having small tuber size and reduce seed tubers infestation by *P. operculella* in the field. Hence, farmers start to plant seed tubers based on rainfall condition from May, first week up to the end of June. According to Gebremedhin *et al.* (2008), earlier June main season planting is preferable since this practice helps the crop to use all conducive environmental conditions in the production season.

Only four respondents harvested seed potato on time, within 120 days after planting, starting mid September. These results indicated that those farmers have got training from HARC. In the study areas, most farmers delay seed potato harvesting practice starting October up to March. Farmes practice delayed harvesting cited the reason due to shortage of labor, and overlapping with the main crop harvesting time. Timely harvested potato helps to prevent the source of infestation in different insect pests, is probably the most important cultural practice for the control of the *P. operculella* (Borgel *et al.,* 1980; Rondon, S.I. 2010).

4.4.2 Seed Potato Source and Storage Methods

As shown in (Table 13) the seed source of potato grown in the study areas vary among the districts. The highest seed source for Welmera and Ejere districts are own and neighbor, while the entire seed potato in self owned DLS storage. However, in Jeldu all sixteen respondents have got seed potato from own and research center. Storing potato either in traditional and improved seed storage is a common practice in the study areas. Majority of the sampled farmers have experience of storing seed tubers in DLS in Jeldu followed Welmera (Table 13). About 43 % and 68 % of the farmers in Welmera and Ejere used DLS storage methods respectively.

TABLE 13: Seed potato source and storage methods used by potato producers in Welmera, Ejere and Jeldu (n=48)

Items	**Major potato growing area**					
	Welmera		**Ejere**		**Jeldu**	
	N	**%**	**N**	**%**	**N**	**%**
Seed source and % of farmers using the source(s)						
Own	2	12.5	1	6.25	-	-
Neighbor	7	43.75	2	12.5	-	-
Own & neighbor	7	43.75	7	43.75	-	-
Own & RC	-	-	4	25	16	100
Own, Ne & Rc	-	-	2	12.5	-	-
Seed storage methods						
On improved storage (DLS)	7	43.75	11	68.75	16	100
Dark place in the house	6	37.50	-	-	-	-
Outside the house	3	18.75	-	-	-	-
Leave un harvested in the field	-	-	5	31.25	-	-

n= number of farmers, RC: Research center, NE: Neighbour

From field and respondents observation the seed source is a major factor affecting getting good quality seed tubers like free of insect pests. The results of this study showed that from the farmers who stored seed tubers under traditional storage methods was highly infested by *p. operculella* than improved storage facilities. However, in Jeldu low *P. operculella* infestation under field and storage condition, thus the majority of the farmers, obtained seed from own and research centers and stored their products in available improved storage facility. Therefore, due to lack of improved storage facility, farmers forced to sell their products immediately after harvest in low price, especially in Beso kebele and these result is similar to (Ayalew *et al.,* 2014b).

4.4.3 *P. operculella* Status and Control Methods in the Study Areas

Occurence of the insect and management practice in the last potato production season is shown in (Table 14). Based on the results of, respondent interviewed occurence pests occurred in last cropping season were *P. operculella*, red ant and wire-worm. However, these result confirms findings of previous research by (Bayeh and Tadesse 1992; Emana, and Amanuel, 1992; Bayeh *et al.,* 2008) as potato pests. All the pest species mentioned above are observed by respondents in Welmera and Ejere districts, while not observed in Jeldu district. However, only two respondents (11.1%) have information on red ant problem on potato production in Jeldu (Table 14). From interviewee five farmers considered *P. operculella* as a serious problem in Welmera on potato production while, in the rest two districts there was problem before two and five years. However, the majority of respondents 16 out of 18 in both districts Ejere and Jeldu reported no problem of *P. operculella* on potato production in (Table 14).

TABLE 14: Insect pest occurrence on potato production, *P. operculella* status and control methods in the three districts, 2014/2015 (n=54)

Problems	**Respondents' interview result**					
	Welmera		**Ejere**		**Jeldu**	
last year pests percent	**N**	**%**	**N**	**%**	**N**	**%**
PTM	5	27.7	7	38.8	-	-
Red ant	3	16.6	-	-	2	11.1
PTM & cutworm	4	22.2	-	-	-	-
PTM & red ant	4	22.2	-	-	-	-
Non	2	11.1	11	61.1	16	88.8
PTM status in the village						
Serious problems	5	27.7	-	-	-	-
Low problems	8	44.4	-	-	-	-
Before two years	3	16.6	2	11.1	2	11.1
No problems	2	11.1	16	88.8	16	88.8
Control methods						
Apply pesticide	5	27.7	2	11.1	-	-
Cultural control	7	38.8	8	44.4	16	88.8
Biological	-	-	-	-	-	-
Pesticide & cultural	6	33.3	1	5.5	1	5.5
Non	-	-	7	38.8	1	5.5

n= number of respondents

From the respondents interviewed and field observation all pests are not serious problems in the study areas. However *P. operculella* was problems on the potato production in Welmera type of storage methods and long history begin potato production. These respondents result agrees with the research results reported by (Bayeh, 2004) *P. operculella* was problem in Welmera and Jeldu before 10 years in potato production. However, now a day in Jeldu, from the interviewed result and field observation shows there was no problem in potato production under field and storage condition. However, based on respondents before two and five years *P. operculella* was serious problem on potato production at that time because farmers used traditional storage methods. Currently, in Jeldu *P.operculella* is not economic pest because the majority of farmers begins to store their products in improved storage (DLS).

In two districts of Welmera and Ejere some farmers attempt to control both *P. operculella* and red ant mainly by using chemical insecticides like malathion under storage and field condition. Kroschel (2003) reported that tubers treat with malathione, *P. operculella* infestation. However, majority of the farmers manage their products through cultural practice such as early harvesting, proper hilling up the tubers, field and storage sanitation and (Raman, 1980).

5 CONCLUTIONS AND RECOMMENDATIONS

5.1 Conclusions

P. operculella is not an important pest at the study areas under field condition on rain fed potato production but, infestation that existed under field condition on Belete potato varieties. *P. operculella* is an economic pest under storage condition at the study sites though the infestation level varies with the type of storage structure and methods. More infestation was recorded in traditional storage methods such as dark place in the house and outside the house covering with straw, while potato tubers stored in DLS was less infested by *p. operculella*. Diffused light storage is a good seed potato storage method and could be constructed, East to West direction to increase refrigeration and reduced tuber moth spread and development. In all type of storage methods *P. operculella* infestation increases with the increase of storage period. Farmers and Developmental agents have little or no knowledge of *P. operculella* damage symptom and its importance in the potato production. Most farmers give more attention to disease like late blight and bacteria wilt rather than *P. operculella*. In the study areas, farmers were practiced cultural control method against *P. operculella* damage on seed tubers under field and storage condition.

5.2 Recommendations

1. In order to reduced *P. operculella* spread and development farmers/growers should adopt good agronomic practice, seed store in proper storage methods and use improved varieties.
2. Awareness creation and training should be given to farmers and developmental agents in order to identify damage symptoms of *p. operculella.*
3. Construction of DLS North to South direction is not recommended because tubers are exposed to sun heat both in the morning and afternoon, so it could be East to West direction.
4. Further study is required to confirm that *P. operculella* is not an economic pests of potato under field condition as this study was a one season study.
5. Integrated Pest Management of *P. operculella* on stored potato tubers should be given research priorities.

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7 ANNEXES

ANNEX 1: Summery table for analysis of variance (ANOVA) for mean infestation of tubers by *P. operculella* at potato harvested.

Number of infested tubers at seed potato harvested

Source	DF	SS	MS	F- value	P- value
Between location	5	427.854	85.571	9.14	0.0001
Within location	42	393.125	9.360		
Total	47	820.979			

Number of active galleries/ tuber at seed potato harvested

Source	DF	SS	MS	F- value	P- value
Between location	5	8.932	1.786	6.52	0.0001
Within location	42	11.506	0.274		
Total	47	20.438			

Number of larvae/ tuber at seed potato harvested

Source	DF	SS	MS	F- value	P- value
Between location	5	1.915	0.383	4.43	0.0001
Within location	42	3.624	0.086		
Total	47	5.539			

Number of infested potato varieties at seed potato harvested

Source	DF	SS	MS	F- value	P- value
Between variety	2	310.499	155.249	13.66	0.000
Within variety	45	511.418	11.365		
Total	47	821.917			

ANNEX 2: Summery table for analysis of variance (ANOVA) for mean infestation of tubers by *P. operculella* at mid seed potato stored in January

Number of infested tubers at seed potato stored in January

Source	**DF**	**SS**	**MS**	**F- value**	**P- value**
Between location	5	6215.417	1243.083	5.82	0.000
Within location	42	8971.250	213.601		
Total	47	15186.667			

Number of active galleries/ tuber at seed potato stored in January

Source	**DF**	**SS**	**MS**	**F- value**	**P- value**
Between location	5	16.190	3.238	9.69	0.000
Within location	42	14.022	0.334		
Total	47	30.213			

Number of larvae/ tubers at seed potato stored in January

Source	**DF**	**SS**	**MS**	**F- value**	**P- value**
Between location	5	0.615	0.123	7.11	0.000
Within location	42	0.726	0.017		
Total	47	1.341			

Number of infested tubers per stores at seed potato stored in January

Source	**DF**	**SS**	**MS**	**F- value**	**P- value**
Between store	3	6207.723	2069.241	10.14	0.000
Within store	44	8978.944	204.067		
Total	47	15186.667			

ANNEX 3: Summery table for analysis of variance (ANOVA) for mean infestation of tubers by *P. operculella* in seed potato storage at next planting season in April.

Number of infested tubers at seed potato stored for next planting season in April

Source	DF	SS	MS	F- value	P- value
Between location	5	12958.167	2591.633	10.49	0.000
Within location	42	10372.500	246.964		
Total	47	23330.667			

Number of active galleries/ tuber at seed potato stored for next planting season in April

Source	DF	SS	MS	F- value	P- value
Between location	5	28.57	5.71	36.56	0.000
Within location	42	6.56	0.15		
Total	47	35.14			

Number of larvae / tuber at seed potato stored for next planting season in April

Source	DF	SS	MS	F- value	P- value
Between location	5	1.624	0.325	7.91	0.000
Within location	42	1.723	0.041		
Total	47	3.346			

Mean number of terminated galleries / tuber at seed potato stored for next planting season in April

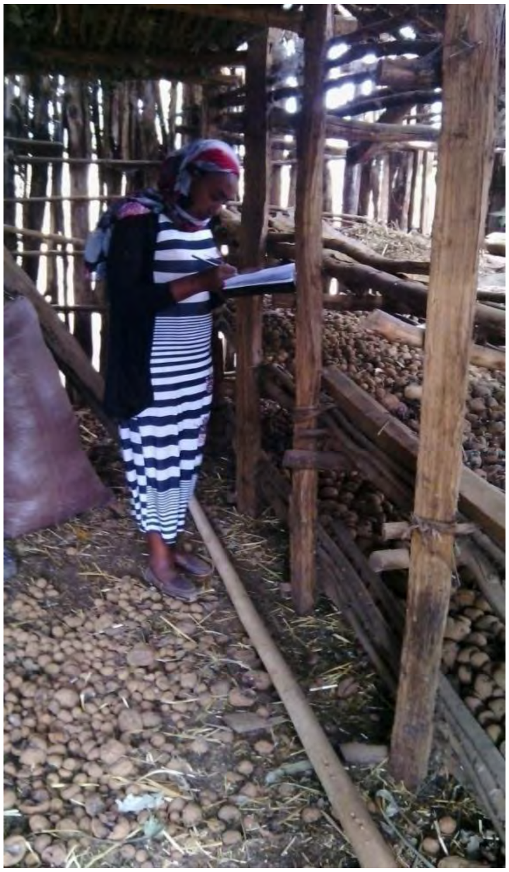
Source	DF	SS	MS	F- value	P- value
Between location	5	0.099	0.020	4.12	0.004
Within location	42	0.201	0.005		
Total	47	0.300			

Mean number of pupae / tuber at seed potato stored for next planting season in April

Source	DF	SS	MS	F- value	P- value
Between location	5	0.041	0.008	3.83	0.006
Within location	42	0.090	0.002		
Total	47	0.131			

ANNEX 4: *P. operculella* field observation at the time of seed potato harvested

ANNEX 5: *P. operculella* larvae at the time of seed potato harvested



ANNEX 6 : Seed tuber observation under storage condition

ANNEX 7: Seed tubers damaged by *P. operculella* at middle and next planting season

ANNEX 8: Seed tubers infested by *P. operculella* stored outside the house

ANNEX 9: Seed tubers infested by *P. operculella,* tubers stored under dark place in the house

ANNEX 10: Seed tubers damage by *P. operculella* tubers kept in high accumulation on shelf and floor.

ANNEX 11: Farmers stored seed tubers under Diffused Light Storage (DLS) methods

ANNEX 12: Questionnaire

Respondent ________________________________Dateof interview________________

District ____________________ Village_______________ Kebele ________________

Interviewer _______________Location _____________________________________

The sample size (whom you will interviewee)

- Extension workers/DA/ (6)
- Ordinary farmers (48)
- 54 total interviewees
- 48 storage facilities were studied and selected randomly using appropriate mechanism.

Interview methodology

- The interview takes place on the farm and in the house of selected interviewee in individual bases.

The type of questionnaires

- Multiple choice
- Numerical open end

I. Socio-Demographic Profile

1) Sex: A Male ☐ B) Female ☐

2) Age: A) 18-29 ☐ B) 30- 50 ☐ C) Above 50 ☐

3) Educational status A) Illiberal (0) ☐ b) Primary school (1-8) ☐

C) Junior secondary school (9-10) ☐ D) Senior secondary school (11-12) ☐

4) Please tell me your tenure/possession/ status.

A) Owner-operator ☐ B) Lease/rent ☐ C) Hired laborer ☐ D) other (specify)

____

5) Are you a member of any farmers' organization?

A) Yes ☐ B) No ☐

6) What farmers' organizations are you a member of?____________________

II. Typical production system to grow potato on your farm

7) Major rotation of the potato grown area:

A) Barley ☐ B) Wheat ☐ C) Bean ☐ D) Teff ☐

E) Non crop land ☐

8) Last cropping season, what potato varieties did you plant?

A) Barley ☐ B) Wheat ☐ C) Bean ☐ D) Teff ☐

E) Non crop land ☐

9) What type of potato varieties planted this season:

A) Gudene ☐ B) Belete ☐ C) Jalene ☐

10) What is your total potato area? _________ ha.

A) 0.25-1ha ☐ B) 1.5-3ha ☐ B) 3.5- 6 ha ☐

C) 6.5-9 ha ☐

11) What cropping pattern do you follow?

A) Potato-Fallow ☐ B) Potato-potato ☐ C) Potato- other vegetable (Specify the vegetable grown) ☐ D) Potato-Other crops (specify) __________

12) (Referring to question number 12) why you select the cropping patter____

13) Typical time of potato planting range (DD: MM – DD: MM):

A) May 10 - May 30 ☐ B) May 10 - June 30 ☐ C) June1 - June 20 ☐

14) Typical time of potato harvest range (DD: MM – DD: MM):

A) Sep.15 - Sep.30 ☐ B) Oc.1 - Oc.30 ☐ C) Oc. 1 - Nov. 30 ☐

D) Oc. 1 - Jau.30 ☐ E) Oc.1 - March 30 ☐

III. Farmers' knowledge on potato tuber moth infestation both at field and storage conditions.

15) What pest(s), if any, did you face in your potato field in last year cropping season?

____

16) Specify the pests, if any, caused the biggest damage to your potato crop last cropping season?____

17) What is your second most important pest problem? ____________________________

18) How did you control these major pests last season?

A) Apply pesticides ☐ B) Cultural control method ☐

C) Biological control ☐ D) Non ☐ E) Other (specify) ________

20) Do you have the knowledge and the damage potential of *P. operculella*?

A) Yes ☐ B) No ☐

21) Why is necessary using any control mechanism for potato tuber moth (PTM)

____

22) How important is potato tuber moth in your village?

A) Serious problems ☐ B) Low problem ☐ C) Before two years ☐

C) No problems ☐

23) When would PTM occur in your surrounding (Specify month etc.)

A) Beginning of September ☐ B) October - April ☐ C) Non ☐

24) In which temperature Zones does PTM occur?

A) Lowland ☐ B) Mid attitude ☐ C) Highland ☐

25) Knowledge on PTM occur in field & storage.

A) Yes ☐ B) No ☐

26) Can you distinguish the damage stage of PTM and can you identify PTM larva from another? How? ____

27) Tuber -feeding insects like PTM cause severe damage to the seed potato crop.

A) Agree ☐ B) Disagree ☐ C) No opinion ☐

IV. Seed potato storage methods and sources

28) Which types of seed potato tuber storage method used?

A) Diffuse light store ☐ B) Dark store ☐ C) in the field, not harvested ☐

D) The dark place in the house ☐ E) Light place in the house ☐

F) Underground pit G) ☐ Potato in the bags ☐ H) Put warm place in the house ☐

I) Cover with crop residues ☐ G) other methods (specify) ☐

29) Which storage methods are best to prevent PTM infestation on

the seed tuber? ______________________________

30) What is your source of seed potato?

A) Private seed grower ☐ B) Ministry of Agriculture ☐ C) Own ☐

D) Neighbor ☐ E) Research center ☐ F) other (specify) ___

31) Of which the above source of seed potato provide free from PTM?

A) Private seed grower ☐ B) Ministry of Agriculture ☐ C) Own ☐

D) Neighbor ☐ E) Research center ☐ F) other (specify) ___

32) What is the consequence of storing infested tubers without proper precautions?

____

33) What is your suggestion concerning potato production in this area.

A) High change ☐ B) Medium change ☐ C) No change ☐

34. Do you give PTM?

A) High priority ☐ B) Middle priority ☐ C) Low priority ☐

D) No priority ☐

The data collection schedule and format

Date of collection______________________________________

The district name______________________________

The name of study site__________________________________

The farmer's name_____________________________________

Type of variety____

Table.1

Number of tubers= 150

Number of tubers	Status of tubers		Terminated galleries per tuber	Active galleries per tuber	Number of larvae	Number of pupa
	Infested tubers	Non infested tubers				

This is my own work in design and in execution to the heart of my knowledge. This thesis is my original work and its composition has never been submitted elsewhere. All sources of materials used for the thesis have been duly acknowledged.

Name	Date	Signature
Mekdes nega	________________	______________

Place: Addis Ababa University, Ethiopia

This thesis has been submitted to examination with my approval

	Date	Signature
Adviser Emana Getu (Dr)	___________	_____________
Examiner Sisay Dugassa (Dr)	____________	____________
Examiner Habte Teike (Dr)	____________	____________