ASSESSMENTS OF PEA WEEVIL (*Bruchus pisorum* L.) IN WEST SHEWA AND EAST ARSI ZONES AND ITS MANAGEMENT USING SOME INSECTICIDES ON FIELD PEA (*Pisum sativum* L.)

M.Sc. THESIS

BY

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By

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A Thesis

Submitted to the Department of Horticulture and Plant Sciences, School of Graduate Studies, College of Agriculture and Veterinary Medicine, Jimma University, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Agriculture (Plant Protection)

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DEDICATION

This thesis work is dedicated to my late father, who was suddenly departed me.

STATEMENT OF THE AUTHOR

I declare that this thesis is my original work which I have submitted it in partial fulfillments of the requirements for M.Sc. Degree at Jimma University, College of Agriculture and Veterinary Medicine. No part and/or all of this work have been submitted in any other University for the academic award of any degree so far. I also declare that all sources of materials used in this thesis are duly acknowledged. Quotations from this thesis are allowable provided scientific rules are fulfilled. I owe right for reproducing all or any part of this work without earlier permission of the author and/or the host University.

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BIOGRAPHICAL SKETCH

The author, Garuma NemeraRoge, was born to his father NemeraRoge and his mother GonfeFirdissaon October 22, 1991 G.C in Bako Tibe woreda, West ShewaZone. He attended his elementary school from 1999-2006 G.C at Sombo Disassa and DembiGobu elementary schools. He then continued his secondary and preparatory school from 2007 to 2010 G.C. at Bako Secondary and Preparatory school in the same woreda, Bako town. The author joined Jimma University College of Agriculture and Veterinary Medicine in 2011 G.C. and graduated with Bachelor of Science in Plant Science on June 27, 2013 G.C. Then he joined Ethiopian Institute of Agricultural Research (EIAR) on May 14, 2014 G.C as a junior researcher. After two years of effective services at HolettaAgricultural Research Center (HARC), he joined the school of graduate studies of Jimma University to pursue his M.Sc.study in 2017.

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LIST OF ABBREVIATIONS AND ACRONYMS

CSA	Central Statistical Agency
D	Dust
DAP	Di-ammonium Phosphate
E	Efficacy
EC	Emulsifiable concentrate
F	Filial generation
HARC	Holetta Agricultural Research Center
m.a.s.l	Meter above Sea level
PA	Peasant Association
Np	Neoplasm
OD	Oil dispersion
PGD	Percent Grain Damage
Pvt.L.C	Private limited company
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SC	Suspension Concentrates
SP	Soluble Powder
SNNPR	Southern Nation Nationalities and Peoples Region
WP	Wettable Powder

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ABSTRACT

*Field pea (Pisum sativum*L.*) is the second most important legume crop in Ethiopia after faba bean. Insect pests are one of the major constraints of field pea production, among which the pea weevil, Bruchus pisorum*L.*, is an economically important pest. This study was conducted to assess B. pisorum distribution and damage level in West Shewa and East Arsi zones of Oromia region, Ethiopia and compare the effects of three insecticides with their respective times of application on B. pisorumunder field condition, at Holetta Agricultural Research Center. Three insecticides: Karate, Coragenand Sevin were applied at flowering, pod setting, and both flowering and pod setting stages of naturally infested field pea plots sown to susceptible variety 'Burkitu'.The survey results revealed that 64% respondents in Cheliya, 60% in Liben Jawi, 50% in Munesa and 56.1% in Lemu Bilbillo districts were not aware about B. pisorum as field pea production constraint. Mean percentage grain damage caused by B. pisorumwere 0.01 ±0.07and0.09±0.24% in Cheliya and Liben Jawi districtsof west Shewa, respectively; whereas grain damage up to 2.11±2.65% was recorded in Munesa. However, the pest was absent in Lemu Bilbillo of East Arsi Zone. The mean grain weight loss caused by the insect was 0.1±0.08% and 0.01±0.05% in Cheliya and Liben Jawidistricts; whereas1.19 ± 1.52% grain weight losses recorded in Munesa district of East Arsi Zone. The results of field experiments revealed that there was no significant (P>0.05) difference among insecticide treatments and control plots. Similarly, insecticide application frequency and crop phenology had no effect on egg and larvae under field and adult emergence of B. pisorum in the storage conditions. This could be due the fact that B. pisorumattack and development occurred at specific crop phenology (usually young pod stage) and lack of fresh attacks on harvested grains either under the field or in the storage conditions. However, both the survey and field studies were conducted for a single season and further studies are needed to explore the effect of prolonged seasons; additionally, screening of more chemical insecticides against the pest both under controlled and field condition are necessary.*

Keywords*:*Coragen, crop phenology, karate, pest management

1. INTRODUCTION

1.1. Background

Field pea is a cool season legume crop that is grown on over 10.12 million ha worldwide (McKay*et al.*, 2003). According to Joshi and Rao (2017), the top ten worldwide field pea producing countries are Canada, Russia, China, India, United States, Ukraine, Tanzania, Australia, Ethiopia, and France. Ethiopia took thesecond rank in Africa and ninth in the world in terms of production. It is grown for different purposes such as edible seed or seed pods, silage and green fodder (Santalla*et al*., 2001), crop rotations to conserve soil water (Biederbeck*et al*., 1995), sustains cropping systems (Jensen *et al*., 2012), fixes nitrogen (Macwilliam*et al*., 2014), reduces insect pests and diseases problems when rotated with cereals (Keneni and Ahmed, 2016) and, it can also be used as cover crop to prevent soil erosion and for soil moisture retention(Angaw and Asnakew, 1994). Moreover, the crop is an important export commodity in international market (Lovett and Gent, 2000; Rashid *et al*., 2015).

Field pea grows in several parts of the country; in the altitude range from 1800-3000 m.a.s.l and annual rain fall of 700-1000 mm (Mussa *et al*., 2003) and ranked as the second most important legume crop in Ethiopia faba bean in terms of both area and total amount of production. About 220,508.39 ha of land was covered by field pea and a total produce of 3, 685, 519.065 t was harvested during 2017/2018 cropping season (CSA, 2018). However, the productivity remains below world average (2 t/ha) (www.fao.org/faostat/en/#data). This might be attributed to biotic and abiotic constraints.

There are many biotic factors that lead to low production and productivity of field pea. Insects such as Pea weevil, Pea leaf weevil, Pea aphid, Armyworm, Lygus bugs and cut worms are major insect pests of field pea. Diseases like powdery mildew, downy mildews, Ascochyta blight, Root rot, Rhizoctonia, seedlingblight, purple blight and Alternaria blight are among the many biotic factors (Hagedorn, 1976; Gorfu and Beshir, 1994; Daniel, 2010).Bruchids are the most important insect pests of food legumes (Bushara, 1988; Kashiwaba, 2003); *Bruchus pisorum*L., *B. pisorum,* became an economically important insect pest of field pea causing significant losses (Clement *et al*., 2000).For instance, in North and South America damage of 42 to 79% (Reddy and Gadi, 2018), in Australia 11-72% (Horne and Bailey, 1991), in Romania 8 to

70% (Sapunaru *et al.,* 1994) and African countries including Ethiopia 8-17% seed weight loss and 48-83% seed infestation (Worku, 2002) reported. Yield losses up to 85% and weight losses up to 59% (Worku, 1998; Seyoum *et al.*, 2012) recorded at Sekota due to damage caused by this insect pest. As a result of the damage, seeds have low market value, less valuable for human consumption and animal feed, and poor in germination rate (Clement *et al.*, 2002; Seyoum *et al.*, 2012).

B. pisorum is a cosmopolitan and most destructive insect pest of the pea cultivars (Clement *et al.,* 2009). The insect is strictly monophagous and completes its univoltine life cycle only on pea crop. Upon emergence from hibernation sites, adult weevil fly into the pea fields and start to search for mate and oviposition sites and, many factors exist in preferring where to oviposit (Mendesil *et al*., 2016). Female insects spend some time in a crop before laying eggs; during this time, they feed on pea pollen to become sexually mature over a period of week (Pajni and Sood, 1975). The larvae, once hatched, burrow through the pod wall into maturing seeds to consume them and complete its development, resulting in loss of yield and quality of pea crop (Michael *et al*., 1993).*B. pisorum*introduced into Ethiopiaduring the mid-1970sand since its first introduction (Assayehegne, 2002; Worku, 2002), the insect is spreading to the nearby regions at a rapid rate pushing local varieties towards extinction (Mihiretu and Wale, 2013). According to Worku (2002), Ethiopian field pea was reported to have suffered from this newly emerged insect since 1992. However, the current status of the pest in field pea producing parts of the country is not well documented.

The management of *B. pisorum* mainly depended on chemical insecticide applications to control the female adults in fields before they lay eggs on pods (Horne and Bailey, 1991; Smith and Hepworth, 1992; Clement *et al.*, 2000; Afonin *et al.*, 2008). Melaku *et al*. (2002) studied trichlorfon 85% WP at a rate of 1.5 kg ha^{-1} to determine critical time of application to manage *B. pisorum*. According to the authors, the insecticide was not effective to manage both adults and eggs of the insect and, screening several other potential insecticides with ovicidal efficiency to manage the insect remained important. In another study done on ovicidal effects of two pyrethroids (*lambda-cyhalothrin* and *alpha-cypermethrin*) and two neonicotinoids (acetamiprid and thiacloprid) insecticides on *B. pisorum* eggs, the pyrethroids were found to be more effective than the neonicotinoids (Seidenglanz *et al*., 2011).

Nikolova (2015) studied the adult and ovicidal effects of six insecticides, namely: -Mospilan 20 SP, Calypso 480 SC, Proteus 110 OD, Duet 530 EC, Nurelle D, and Fury 10 EC against *B. pisorum* and, the author found Mospilan 20 SP and Fury 10 EC inhibited further oviposition and induced egg mortality. Even though the two insecticides (Mospilan 20 SP and Fury 10 EC) were the most effective insecticides from neonicotinoids group, all the insecticides were found having the ability to cease additional oviposition by *B. pisorum* due to their toxic effect on the insect. Despite the screening of different host plants and breeding efforts for resistance against *B. pisorum*, no resistance has been reported in cultivated pea varieties though moderate levels of resistance have been reported in *Pisum fulvum*germplasm (McPhee, 2003; Aryamanesh *et al*., 2012). As to the efforts for the biological and cultural controls of the insect, no effective biological or cultural controls existed (Bragg *et al.*, 2000).

From the assessments of *B. pisorum* in East Shewa, South West Shewa, East Arsi and North Shewa of Oromia Regional State and Gurage, Wolaita, Sidama, Gedeo and Dawuro zones of Southern Nation Nationalities and Peoples Region (SNNPR) in Ethiopia; in East Shewa (Nazreth, Mojo, Wolenchiti, Debre Zeitand Ejere) areas and in South West Shewa (Welisso, KersaMalima, Teji, Asgori and Leman), in East Arsi (Kulumsa), in North Shewa (Arerti) and in ButaJira of Guragezone of SNNPR the insect was recorded (Ali, 2015; unpublished data). However, information on current distribution, damage level and pest management methods arelimitedin most areas where the insect was reported.It is therefore, important to assess the current distribution and damage level of the insect in areas previously assessed and untouched close sites as the insect is mainly distributed through infested seeds.

The infestation by*B. pisorum* starts in the field when adults first lay their eggs, andconsequentlyadults will be in the pea field starting from the crop’s flowering stage up to pod setting stage, and as such, repeated application of insecticides are required to control the adults or kill the eggs that are laidat pod forming stage of pea crop. Therefore, generating information on the efficacy of existing insecticides against theinsect became important and in light of the above information, the current research wasconducted with the following objectives.

1.2. OBJECTIVES

- To assess the current distribution and damage of *B. pisorum*in West Shewa and East Arsi Zones of Oromia Regional State, Ethiopia.
- To determine the best time of application of the effective insecticide to control*B. pisorum* in the field, at Holetta Agricultural Research Center.

2. LITERATURE REVIEW

2.1. Origin and distribution of *B. pisorum*

Species of Bruchus (Bruchinae), formerly considered a distinct family, the 'Bruchidae' are chrysomelid beetles whose larvae develop inside seeds (Kergoat *et al*., 2007). Bruchus spp. are most common in the Palearctic region, but some species occur in North America, Africa and Australia as introduced species. Several species are agricultural pests of legume seeds (Kergoat *et al*., 2007). *B. pisorum* is a major pest of field pea in most regions of the world where field peas are grown (Clement *et al*., 1999). The native range of *B. pisorum* is not certain, but it likely evolved in the same geographical region as its host, field pea (Byrne, 2005). According to (Byrne, 2005; Afonin *et al*., 2008) in Reddy *et al*. (2017), the origin of peas is believed to be the middle Asia, including north-west India and Afghanistan and also a second area of development lies in the near East, and a third includes the plateau and mountains of Ethiopia.

The insect was first mentioned in the early 18th century by Swedish traveler Kalm (Larson *et al*., 1938). However, its first record as a pest was in South Africa in the Cape Province (Skaife *et al*., 1918). In 1931, it was established as insect pest in Australia (Newman, 1932). It is proposed that infested seeds are the cause of expansion of this pest to Europe, America, Africa and the Australian sub-continent (Clement *et al*., 2000). *B. pisorum*'s ability to withstand extended periods of dry conditions has contributed to its successful expansion (Hardie, 1992).

The presence of this insect is reported in different parts of the world in different years with varying status of distribution within the countries where it was reported. For instance, Bangladesh (Bashar and Fatema, 1994), China (APPPC, 1987), Hong Kong (Hong Kong Government Information Centre, 2003), India (Pajni and Sood , 1975), Iran (Abivardi, 1976), Iraq (Al-Rawy and Kaddou , 1971), Japan (Lincoln Plant Protection Centre, 1985), Ethiopia (Assefa *et al.* , 2003), Nigeria (Olaifa, 2000), USA (Idaho) (Pesho *et al.* , 1977), Oregon (Systma *et al*. , 2003), Austria (Weinhappel *et al*. , 1996), Slovakia, and in many other parts of the world (Fig1). At the moment, *B. pisorum* is a major menace in most field pea growing regions in the world (Teshome, 2015). Though *B. pisorum* was first documented in Ethiopia in 1985, it was most likely accidentally introduced to Ethiopia during 1970s with food aid received by Ethiopia during the severe famine the country experienced that period (Scheepers, 2012). From 1992, *B.*

pisorum has been reported to be a substantial insect pest of field peas in North West Ethiopia (Esmelealem and Melaku, 2013), with the insect found in the warmer areas around Bahir Dar and the highlands of Motta.

Figure 1. Global distribution of *B. pisorum*

Source: https://www.cabi.org/isc/datasheet/9907#todistribution.

2.2. Description and biology of *B. pisorum*

B. pisorum is a univoltine bruchid first described by Linnaeus in 1758 as *Dermestes pisorum*. However, Linnaeus later created the Bruchus genus which included *B. pisorum*. The adult is a chunky beetle about 5 mm long, generally brownish marked with white, black and grey patches. The tip of the abdomen extends beyond the wing covers and is white marked with two black oval spots. The egg is yellow, cigar-shaped and measures 1.5 mm by 0.6 mm. The larva is a legless, curled, cream grub which grows to about 5 mm long (Baker, 1998). The female weevils are slightly bigger in size than the male counterparts. The male can be distinguished from the females by their tiny spine located on the distal end of the tibia of the middle leg (Larson *et al*., 1938). The antennae of the *B. pisorum* are as long as one third of its whole-body length.

Pollen is necessary for *B. pisorum* before oviposition; adults first feed on pollen of pea flowers, mate, and oviposit (Blodgett, 2006). Upon leaving hibernation, only the male is sexually mature. Pollen feeding courage the mating of adult males and meanwhile it increases their mating frequency after pollen feeding (Ceballos *et al*., 2015). Adults also feed on petals, calyx and nectar although pods which have nearly reached their maximum size and are still tender are preferred (Clement *et al*., 2002). Volatile cues from pods are responsible for attracting *B. pisorum* females more than other phenological stageswhile the number of eggs laid on each pod depends largely on the local weevil population size (Ceballos *et al*., 2015). Several larvae often enter the same seed, but only one adult has been observed to emerge, and while the reasons for this are not completely explored, density dependent mortality seems to occur in the third instars (Smith and Ward, 1995). Late pupating larvae emerge from threshed pea seeds about 30 days after harvest (Blodgett, 2006). Pupae become adults in about two weeks, and total developmental time from egg laying to adult emergence is 7-12 weeks (Reddy *et al*., 2017). Both adults and larvae feed on the inside of seeds, the damage is distinctive; feeding causes tiny dot-like entrance holes, larger round exit holes with a diameter of 2.5 mm and excavated seed, and large populations may reduce stored crop to almost dust (Sarwar, 2015).

Despite having the title of weevil, *B. pisorum* does not possess snout which is typical characteristics for most true weevils (Newman, 1932). Infestations of *B. pisorum* can only occur if eggs are laid on green pea pods in the field. According to study on biology and ecology of *B. pisorum* by Assayehegne (2002), the females of *B. pisorum* can lay up to 60 eggs on a single pod and the eggs are laid singly on green pods of thecrop. He also found *B. pisorum* to undergo complete metamorphosis and accordingly, the insect had four instars. According to the author, control measures which target at preventing the insect before it lays eggs should be practiced since control of larvae in infested seed will be difficult.

B. pisorum feeds on pea flower and the life and reproductive success of this insect is a function of the pea flower nectar and the qualities of flowers and their organs like petals (Clement, 1992). The insect is a monophagous insect pest and it is a field pea specialist. In study conducted to determine whether *B. pisorum* really attacks only *P. sativum* or can attack other leguminous crops through mixed sowings of several cultivated leguminous crops and some wild species, it was found that the insect preferred and attacked only pea crop. The study also confirmed that the females of the insect did not oviposit on other legume crops sown with pea crop and the insect is thus monophagous pest of field pea crop (Burov, 1980).

2.3. Importance of field pea, *Pisum sativum* L.

Field pea is a cool-season annual vine crop currently grown in temperate regions at high elevations, or during cool seasons in warm regions throughout the world. Dry peas accounted for eight percent of the world's area under pulses in 2011-2013 and in 2013; the vegetable pea production amounted to 17.43 Mt worldwide (Elzebroek, 2008).

Field pea is primarily used for human consumption or as a livestock feed. The crop is commonly used throughout the world in human cereal diets (McKay *et al*., 2003). Field pea is known for its high levels of amino acids, lysine and tryptophan, which are relatively, low in cereal grains. Protein content up to 25%, total digestible nutrients up to 87%, high levels of carbohydrates and low fiber contents are among the nutritional benefits of field pea (McKay *et al*., 2003).

In developing countries, dry peas accounted for only four percent of area under pulses in 2011-2013 (Joshi and Rao, 2016). Field pea is a common and widely consumed pulse crop in cool highlands of Ethiopia. The crop is an important source of food and feed with a valuable and large source of protein. It plays a significant role in soil fertility restoration through biological nitrogen fixation and it sustains cropping systems (Jensen *et al*., 2012; Musa *et al*., 2003). Field pea is also known for its role as a break crop for pest and pathogen pressure reduction (McWilliam*et al*., 2014). It is also a good source of cash to the producers (Musa *et al*., 2003).

Field pea is well-adapted to cool, semiarid climates. According to Alem and Asres (2005) and Humplik *et al*. (2015), field pea requires cool, moist growing conditions and can withstand heavy frost once established. It does not grow well in hot weather and its germination can occur at temperatures as low as 4.4^0C, although optimal temperatures for germination and growth are between 15.5 and 21.1^0C (Pavek, 2012), but generally grows best between 10^0C and 20^0C (Velykis and Satkus, 2012). Field peas are adapted to many soil types, but grow best on fertile, light-textured, well-drained soils (Hartmann *et al.*, 1988; Elzebroek, 2008). Field peas are sensitive to soil salinity and extreme acidity. The ideal soil pH range for pea production is 5.5 to 7.0 (Hartmann *et al*., 1988). Field pea is not shade-tolerant and shows little salinity tolerance (Ortiz, 2013). Ethiopian field pea is highly suitable for cultivating on the soils with low fertility, such as those in northern Ethiopia, where it achieves better results on field pea and other cool season legumes (Gebreslassie and Abraha, 2016).

2.4. Impact and economic losses of field pea due to *B. pisorum*

The human consumption and pea market have a nil tolerance for live or dead *B. pisorum*, while the stock feed market has nil tolerance for live *B. pisorum*. The circular cavities in the damaged pea grains are visually unacceptable for human consumption and also affect sprouting percentages. Grains with damage will be downgraded and it produces non-viable and/or weak seedlings (Armstrong and Mattew, 2005).

Weight loss and reduced germination percentages are the key damage effects of *B. pisorum*. Both of these losses increase as immature *B. pisorum*stages develop, reaching their maximum when the larvae are mature. Bekele *et al*. (2006) reported crop losses of up to 80% in the Ebinat and South Gonder and 45% in the WagHimra areas.

Generally, damage to crop is caused by the larvae, which destroy most of the grain during their full development; affecting the seed embryo. Thus, some workers suggest that insecticide should be applied during bloomonce the majority of the adults have entered the fields but prior to egg laying (Patrick *et al*., 2018). Many authors have found that *B. pisorum* could cause enormous damage to yield potential, reducing the grain yield by 40% or more (Alekhine and Ivanova, 2007). The insect can also host parasitic itch mite which can cause allergic skin reactions in humans (Armstrong and Mattew, 2005).

2.5. Management practices of *B. pisorum*

2.5.1. Cultural

Cultural control is the deliberate alteration of the production system, either the cropping system itself or specific crop production practices, to reduce pest populations or avoid pest injury to crops (Ferro, 1996). Field sanitation by destroying crop residues, preventing shattering at harvest and eliminating volunteer plants can reduce infestation (Blodgett, 2006). Early planting and harvesting are effective because of a general lack of other host plants (Smith, 1990; Mendesil *et al*., 2016a). Other cultural control practices such as crop rotation and intercropping can help in the increment in the productivity (Mendesil*et al*., 2016a). Trap cropping using surrounding buffer strips or intercropping pea fields with non-crops or pea varieties that are highly attractive to *B. pisorum*is useful in managing the insect though the dependence on this option needs further research (Mendesil *et al*., 2016b).To avoid the persistence of infested seeds, peas grown for hay purpose should be cut soon after the beginning of flowering (Baker, 1998; Scheepers, 2012). Destruction of infested stored peas is also an additional and important cultural measure that can be useful (Reddy *et al*., 2017).

2.5.2. Biological

Several studies have documented potential biological control agents for *B. pisorum*. Study done in North West United States showed that the survival of *Eupteromalus leguminis* (Hymenoptera: Pteromalidae) depends on development of *B. pisorum* to the fourth instars though no effective parasitism was found from this parasite insect (Baker, 1990a, 1990b). *Triaspis thoracica* (Hymenoptera: Braconidae), which attacks the early stage larvae of the insect within the seed, has been reported to attack about 15 species of Bruchus in France (Nikolova, 2016a).

Several species of *Uscana senex* (Hymenoptera: Trichogrammatidae) are egg parasitoids of various families of Coleoptera (Huis *et al*., 1990). *U. senex*wasreported to cause 50-80% parasitism, and it reduced seed damage by 70% in Chile after its introduction in 1987 (Hormazábal and Gerding, 1998). In Chile, these parasitoids are released twice weekly at the beginning of flowering until the pea pods are completely filled.*U. senex* has also displayed a degree of dispersal ability, although distance certainly influences the level of parasitism; as the distance from the release point increases, the level of egg parasitism decreases (Hormazábal and Gerding, 1998). Commercial production of Trichogramma spp. for the biological control of *B. pisorum*in Brazil was also reported by Parra (2014).

2.5.3. Host plant resistance

The mechanisms underlying resistance to *B. pisorum* act at both the seed (seed coat and cotyledons) and pod levels (Hardie, 1992). Other research indicates that resistance in pea varieties is related to pod length; which has effect on oviposition (Hardie and Clement, 2001). Laboratory and glasshouse bioassays have been developed in Australia and the United States for evaluating P. *fulvum* accessions for resistance to *B. pisorum*. Swollen *P. sativum* pods as long as about 2 cm were found to provide optimal oviposition substrates. Dual-choice and no-choice laboratory bioassays are now developed using these traits to screen *P. fulvum* accessions (Hardie and Clement, 2001).

Molecular-marker screening or single-plant selection using a glasshouse bioassay is other ways to develop resistant varieties of peas (Aryamanesh*et al*., 2012). High levels of insect resistance have been reported in the wild relatives of peas (Clement, 2002; Sharma *et al*., 2005). Wild species are a non-preferred plant as a site for oviposition by *B. pisorum* (Ali *et al*., 1994); therefore *P. fulvum*has been used as a source of resistance to *B. pisorum* in breeding programs (Byrne, 2005).*P. fulvum* accessions have been screened under field conditions for their susceptibility to *B. pisorum* (Hardie *et al*., 1995) and, variation in their levels of resistance to oviposition has been observed (Clement *et al*., 2002).

Dochkova and Ilieva (2000) found that cultivars and lines of pea containing condensed tannins in the pod, grain coat, or interior, were more resistant to attack by *B. pisorum.*Bruchins, conditioned by Neoplasm allele (*Np*) is a formation of callus or neoplasms; induced resistance mediated by a class of natural products of lipid origin that are found in *B. pisorum* (Doss *et al*., 2000). These are potent plant regulators and are found to cause neoplastic growth in small amounts on pods of all *P. sativum* lines tested in Doss *et al*. (2000). Teshome *et al.* (2016) reported promoting*Np* formation under field conditions by intercropping peas is an appropriate means of managing *B. pisorum.*

Mendesil*et al*. (2016b) found that female weevils preferred ‘Adet’ (an improved variety of pea) for oviposition, likely due to differences in pod features such as trichome number, wax and pod wall thickness, when compared with non-host leguminous plants such as wild pea,*P. fulvum*, and grass pea, *Lathyrus sativus*. Nikolova (2016b) compared the response of five peas (*P. sativum*) varieties, viz. Glyans, Modus, Kamerton, Svit and Pleven 4 and found that the spring pea cultivar ‘Glyans’ was only weakly preferred by *B. pisorum* for oviposition in breeding programs. Byrne *et al.* (2008) demonstrated that seed resistance to larval *B. pisorum*attack is more sustainable than the pod resistance to *B. pisorum*oviposition as an effective defensive trait in hybrid pea varieties. This is because pod resistance, which is quantitatively inherited in the F2 population, is greatly reduced in the F3 and subsequent generations, while seed resistance remains present and effective in the F4 and F5 generations. However, study by Clement *et al.* (2009) showed that pod surface characteristics increase neonatal larval mortality; seed resistance was not broadly transferred to inter-specific progeny.

2.5.4. Botanical

Plant extracts have potential for use as pesticides against*B. pisorum.* The oil of *Putranjivaroxburghii*seed coat effectively repelled *B. pisorum* adults from infesting seeds of *Dalbergiasissoo* (Roxb) (Kumar, 2014). Oils of several aromatic plants such as *Thymus vulgarus* L. (Lamiales: Lamiaceae), *Santolinachamaecyparissus*L. (Asterales: Asteraceae) and *Anagyrisfoetida* L. (Fabales: Fabaceae) control *Callosobruchus chinensis* L. (Coleoptera: Bruchidae), another seed-infesting beetle, and these oils could also be used against *B. pisorum*. Plant extracts such as Pyrethrum (a neurotoxin), *Acanthrospernumhispidum* (antifeedant), *Trichiliaheudelotii* (antifeedant), Vernonia spp. (neurotoxin), pyrethrin, *Lippiaadoensis* (a neurotoxin), *Piper guineanse* (a fumigant), and garlic (a repellant) can be used against *B. pisorum* before egg laying occurs (Olaifa, 2000).

2.5.5. Chemical/Insecticides

The basic method of *B. pisorum* management is still through chemical control, which is aimed at controlling adult beetle density in a crop before they lay eggs on pods (Horne and Bailey, 1991; Smith and Hepworth, 1992). However, the efficacy of the chemical control treatment is largely determined by the timing of spraying which coincides with female egg laying, which is difficult to determine.

The feeding location of *B. pisorum*larvae within the seed makes infestation levels in crops difficult to monitor. Control of adults is most effective if pesticides are applied before females lay eggs, which starts when the crop comes into bloom (Clement *et al*., 2000; Scheepers, 2012). However, adults are present in pea fields for a long period, and repeated chemical applications are required to prevent seed infestation (Baker, 1998).

Esmelealem and Melaku (2013) observed the contribution of grain fumigation in reducing the future inoculums of already infested field pea seeds than directly trying to control the insect in the field. The result of the study showed that fumigation could reduce the future carryover of the insect. McDonald (1995) and, Williams and Whittle (1994) studied the effect of fumigation on *B.*

pisorum and, they found fumigation could reduce the damage because it is applied soon after harvest. The study however, could not witness managing the insect in the field. So, periodic application of contact-pesticides to pea fields is the most common strategies for chemical control of *B. pisorum* (McDonald, 1995; Aryamanesh *et al*., 2012; Esmelealem and Melaku, 2013).

A variety of insecticides in different chemical groups have been found to be effective against*B. pisorum* (Smith, 1990; Horne and Bailey, 1991; Blodgett, 2006). In field trials and subsequent laboratory bioassays to see the effects of cypermethrin, endosulfan, methomyl and fenvalerate, it was found that cypermethrin reduced damage by *B. pisorum* in sprayed plots than endosulfan and fenvalerate as compared to unsprayed plots (Horne and Bailey, 1991). The same study observed the action of these insecticides in laboratory by exposing the adult insects to leaves of peas treated with cypermethrin at the rates used in the field and it was found that cypermethrin again acted by knocking down the insects. It was concluded from the study that the insecticide acts as knockdown insecticide against *B. pisorum* in field and under lab conditions (Horne and Bailey, 1991).

Different insecticides were registered for the management of *B. pisorum*mainly in the field conditions. For instance, Phosmet (Imidan 70 WP) in combination with Dimethoate application at 50 percent bloom was found to be effective both for *B. pisorum* and Pea aphid. For large commercial fields, the insecticides were sprayed with tank as locating the insects in the field is very hard (Bragg *et al.,* 2000). Cyfluthrin (Tombstone), Alpha-cypermethrin (Fastac EC), Malathion (Fyfanon) and Carbaryl were among the insecticides tested for the management of *B. pisorum (*https://pnwhandbooks.org/insect/legume-grass-field-seed/pea/dry-edible-seed-pea-pea-weevil; retrieved on 13August 2019).

3. MATERIALS AND METHODS

3.1. Description of the study area

The study was conducted in two selected zones: West Shewa and East Arsiof Oromia Regional State, Ethiopia (Fig 2). Four districts, two from each zone were purposively selected based on their field pea productionpotential. The districts from both zones are mainly characterized by production of stable crops such as wheat, teff, faba bean, field pea, barley and others (Appendix table 4). The study was conducted between 2017 to 2018.

Table 1. Geographical and climatic features* of the study areas

Sampling Zones	Districts	Coordinates: Latitude/Longitude	Mean Altitude (m.a.s.l)	Mean annual rainfall (mm)	Temperature range (ºC)
West Shewa	Cheliya	9º 00'20.010"N 37º27′53.676″E	2591	950	18-28
	Liben Jawi	9º 00'24.012"N 37º27′43.102"E	2630	1000	15-25
East Arsi	Munesa	7º 32'15.408"N 38º58'51.990"E	2720	1020	10-25
	Lemu Bilbillo	7º 32'33.570"N 39º15'49.992"E	2878	1033	10-25

*Data collected during survey in 2018.

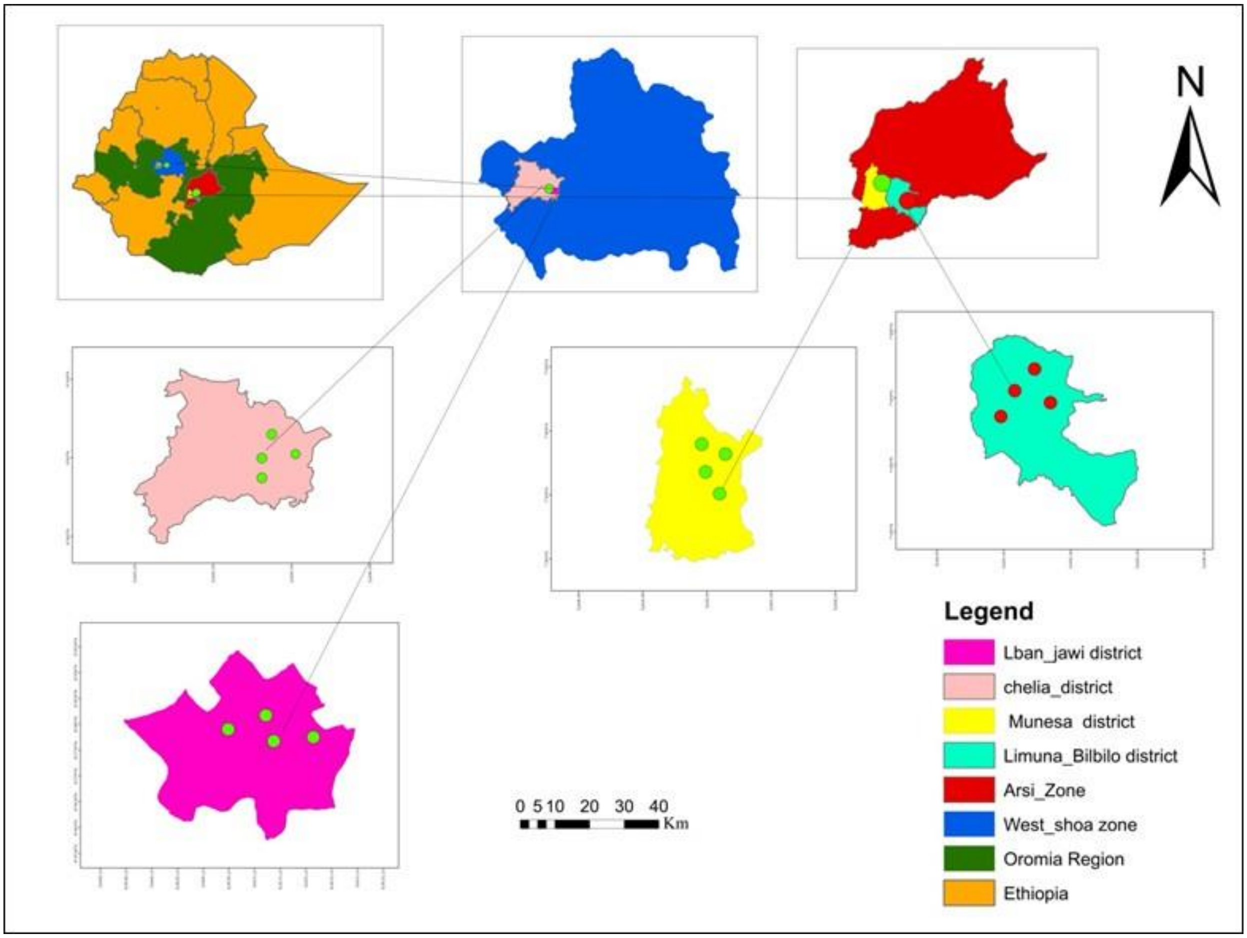

Figure 2. Map of the survey areas

3.2. Observational Study

3.2.1. Sources and Types of Data

Both primary and secondary sources of data were used for the study to generate information in the study area. Primary data were collected through face to face interviews and observations. Semi-structured questionnaire was prepared to collect the required data fromfield pea producers in four rural peasant associations, PAs.The questionnaire was also included to collect farmers` knowledge, perception and practicesabout the insect (Appendix table 1).Secondary data were gathered from zonal reports, district agriculture offices, and developmental agents.

3.2.2. Sampling procedures and sample size

The target populations for this study were farmers who potentially produce field pea. Purposive and three stage sampling strategy was used to select representative sample of grain storing farmers from the study area. In the first stage, two districts were purposively selected from each of West Shewa and East Arsi zones based on the production potentials. In the second stage, in consultation with district experts, from each district four PAs were randomly selected as the representative of the districts; in each district field pea was a common crop produced. In the third stage, a total of 386 field pea producer farmers of four districts (Appendix table 2)were proportioned into the representative PAs using the formula of Yamane (1967).Samples of field pea grains were collected from each household and, percent grain damage and grain weight losses weredetermined after the samples were diagnosed of the Pea weevil infestation.

$$\mathbf{n} = \frac{\mathbf{N}}{\mathbf{1 + N\ (e)^2}}$$

where; N=the size of population; n=the sample size;e=error of 5 percentage points.

3.2.3. Assessment of grain damage and grain weight loss

Percent grain damage and grain weight losses were calculated according to Khattak*et al*. (1987) and Gwinner *et al.* (1996), respectively; viz,

$$\text{Insect damaged grain (\%)} = \frac{\text{Nds}}{Tns} \times 100$$

Where; Nds = number of damaged seeds, Tns = total number of seeds.

$$\text{Percent grain weight loss} = \frac{(\text{W}\mu * \text{Nd}) - (\text{Wd} * \text{N}\mu)}{\text{W}\mu * (\text{Nd} + \text{N}\mu)} * 100$$

where; Wμ = weight of undamaged grains; Nμ = number of undamaged grains; Wd = weight of damaged grains; Nd = number of damaged grains.

3.3. Field Experiment

The experiment was conducted during the main cropping season of 2017/2018 atHoletta Agricultural Research Center (HARC) field experimental site. The center is located at about 29 km to the west from Addis Ababa and 9º 00' N latitude and 38º30' E longitude with an elevation of 2400 m.a.s.l (http://www.eiar.gov.et/holetta). Agro-ecologically, the site is highland with average minimum and maximum annual temperature of 6.6^{0}C and 24.13^{0}C, respectively. The area receives mean annual rainfall of 1071.6 mm and average relative humidity of 55.75% (Appendix table3).

3.3.1. Experimental materials and design

Susceptible field pea variety called 'Burkitu' and three insecticides at their manufacturers' rate wasused as experimental materials. 'Burkitu'variety is susceptible to *B. pisorum* and usually has been used as check in other varietal screening activities (HARC, 2015). The details of the insecticides used were as indicated in Table 2, below.

Table 2. Description of the Insecticides used as in the treatments

Trade names	Common names	Rates (formulation/ha)	Manufacturer/supplier
Karate/Highway® 50 EC	Lambda-cyhalothrin	400 ml	Syngenta Agro services Ag.
Coragen ®200 SC	Chlorantraniliprole	250 ml-375 ml	Chemtex Pvt.L.C.
Sevin 85%WP	Carbaryl	1.5 kg	Bayer Crop Science-Germany

The design of the experiment was Randomized Complete Block Design (RCBD) having ten treatments arranged in such a way that the three insecticides were applied at different phonological stages (flowering, pod setting, and both at flowering and pod setting stages) of pea crop (Table 3). The ten treatments were replicated four times.

Table 3. Treatments details

Insecticides	Times of application/Crop stages	Treatment codes*
	At flower stage	K(F)
Karate/Highway® 50 EC	At pod stage	K(P)
	At both flower & pod stage	K(F+P)
	At flower stage	C(F)
Coragen ®200 SC	At pod stage	C(P)
	At both flower & pod stage	C(F+P)
	At flower stage	S(F)
Sevin 85 %WP	At pod stage	S(P)
	At both flower & pod stage	S(F+P)
Untreated		Control/unsprayed plot

Key: *KF=Karate at flowering stage, KP=Karate at pod setting stage, K (F+P) =Karate at both flowering & pod setting stages, CF=Coragen at flowering stage, CP=Coragen at pod setting stage, C (F+P)=Coragen at both flowering & pod setting stages, SF=Sevin at flowering stage, SP=Sevin at pod setting stage, S(F+P)=Sevin at both flowering & pod setting stages.

A field pea variety 'Burkitu' was planted ona plot of size 1.5 m x 0.8 m = 1.2 m^2 with spacing of 20 cm and 5 cm between rows and plants, respectively. The buffer spacing was 1 m and 1.5 m between plots and adjacent replications/block, respectively. All the plots were maintained under natural infestation by adult *B. pisorum.* Inorganic fertilizer, DAP, was used at 100 kg ha^{-1} and all other agronomic practices were done as recommended for the crop in the area.

3.3.2. Data Collected

Number of adults,eggsand ovicidal effect of the insecticides: Before the second spray at pod setting stage, pods were carefully assessed and estimates of adult *B. pisorum*density in experimental field was made by taking 25 sweeps with a sweep net following the insect's threshold level (Baker, 2016). Ten plants from each middle row were selected and ten pods with eggs were tagged and the number of eggs from each pod was recorded. After applying the second spray, post-spray egg count was made to see the ovicidal effect of the insecticides.

Number of larvae: Number of larvae was counted by dissecting 50 dry seeds taken randomly from each tagged pod at harvest.

Number of adults emerged: Fifty-gram seeds from each treatment were randomly taken and allocated per experimental unit (a plastic jar of 250 ml; 6 cm x 7 cm). Thejarswere inspected on daily basis for the emergence of adults. The temperature (ºC) and relative humidity (%) of the laboratoryroom was recorded using thermo-hygrometer on daily basis until the end of the experiment (Appendix Figure 1).

Days to adult emergence: The number of days required to adult emergence was recorded daily starting from harvest until the first adult emerged from seeds in each treatment.

Percent grain damage (%): The percent grain damagewas calculated by separating healthy grains (without holes) from the sieved samples and used for percent damage calculations using the formula described by Khattak*et al.* (1987).

Grain weight loss (%): After separating grains into damaged grains with exit holes and undamaged grains, grains with and without exit holes were counted and weighed separately and the obtained data were used to calculate the percent grain weight loss. The percent grain weight losses were determined by the count and weigh method of Gwinner *et al.* (1996).

$$\text{Percent grain weight loss} = \frac{(\mathrm{W\mu} * \mathrm{Nd}) - (\mathrm{Wd} * \mathrm{N\mu})}{\mathrm{W\mu} * (\mathrm{Nd} + \mathrm{N\mu})} * 100$$

Thousand seed weight (g): Clean, 1000 grains were taken from each treatment and weighed in gramafter adjusting the moisture content to the standard level, 10% (Cassells and Armstrong, 1998).

Yield (Kg/ha): Yield per plot at harvest was taken and converted into ha.

Phytotoxicity assessment: The score was made after each spray based on pesticide efficacy testing protocol and procedures for registration of pesticides in Ethiopia (Lavadinho, 2001; Deneer*et al.*, 2014) for leaf scorch based on leaf scorch scale of 0-3; where 0 = no symptom, 1 = light, 2 = medium, 3 = heavy scorching.

Effectiveness of the treatments: Mean of egg counts before and after the second-roundspray were subjected to percent efficacy calculation using Abbott’s formula (1985).

$$\text{Efficacy (\%)} = [1 - \frac{(\mathrm{Ta} * \mathrm{Cb})}{(\mathrm{Tb} * \mathrm{Ca})}] * 100$$

where; Ta=Post-treatment population in treated plot, Cb=Pre-treatment population in check, Tb= Pre-treatment population in treated plot, Ca= Post-treatment population in check.

Germination test: Germination test was done to observe the effects of the treatments on the crop's seed viability. Fifty grain were randomly selected from each treatment and placed on moist filter paper on petridish for seven days as used in Gwinner *et al*. (1996).

3.3.3. Data Analysis

The questionnaires were grouped into five major inclusive questions: seed source, general knowledge of the households on field pea pests, specific knowledge of the households on field pea insects, pest management practices on field pea, and storage types used for field pea crop to summarize the households' responses. Descriptive statistics such as mean, standard error, percentage and frequency distribution were used to analyze the survey data. Chi-square and t-test were employed to test the statistical significance for both dummy and continuous variables.

Table 4. Summary of the hypothesis of leading questions of both categorical and dummy variables used in the analysis

Variable	Type	Measurement
Seed source	categorical	1=own it myself, 2=from other farmer, 3=market, 4=seed enterprise/farmers' association, 5=bureau of agriculture
Do you know any problems (diseases/insects, etc.) on this crop when it is in the field or after harvest?	dummy	1=yes, 2=no
Do you know any field pea insect pest?	dummy	1=yes, 2=no
Pest management methods	dummy	1=yes, 2=no
Storage type	categorical	1= bin, 2=sack, 3=underground, 4=plain ground

For the field experiment, data on larvae count, number of adults emerged, percent grain damage, grain weight loss and germination test were square root transformed after normality test to fit/satisfy assumptions of Analysis of Variance (Gomez and Gomez, 1984). The transformed data were then subjected to ANOVA, i.e., the procedure of general linear model (proc glm) to determine the treatment effects using SAS v. 9.3 (SAS, 2011) software. Least significant difference (LSD) at 5% probability levelwasused for mean separation when proved significant and or highly significant. Therefore, the ANOVA model is: -

$$\mathbf{Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}}$$

where: Y_{ij} is the jth observation of the i^{th} treatment, μ is the overall mean, τ_i is the treatment effect of the ith treatment, β_j is the rep/block effect of the j^{th} replicate, and ε_{ij} is the random error associated with i^{th} treatment and j^{th} replicate.

4. RESULTS AND DISCUSSION

4.1. The survey results of *B. pisorum*

4.1.1. Distribution of *B. pisorum* in study areas

From the assessments made in four districts, *B. pisorum* was found in Cheliya and Liben Jawi districts of West Shewa zone. However, the insect was found only in Munesa district from East Arsi zone.

4.1.2. Farmers practices, knowledge and perceptions on *B. pisorum* in the study districts

The summary of descriptive statistics indicated that there was significant difference among study districts on seed source and knowledge of field pea insect pest. There was significant difference on knowledge of pests of field pea crop between Cheliya and Liben Jawi districts. However, there was no significant difference between Munesa and Lemu Bilbillo on the knowledge of pests of field pea. There was significant difference between Cheliya and Lemu Bilbillo districts on responses given to pest management practices on field pea. The mean difference ofresponses given to storage types significantly different among Cheliya, Liben Jawi and Munesa districts. The mean of responses given for the storage type was non-significant between Cheliya and Lemu Bilbillo (Table 5).

Table 5. ANOVA of multiple comparisons of survey districts on descriptors/variables of *Bruchus pisorum* infestation

Variables	District (I)	Districts (J)	Mean	Mean Difference (I-J)	S.E.	P-value
Seed source	Cheliya (N = 86, Mean = 1.00)	Liben Jawi (N = 85)	1.00	0.000*	0.086	1.000
		Munesa (N = 108)	1.33	-0.333*	0.081	0.000
		Lemu Bilbillo (N = 107)	1.06	-0.06*	0.081	0.900
Knowledge about the general pestsof field pea	Cheliya (N = 86, Mean = 1.64)	Liben Jawi (N = 85)	1.60	0.040*	0.076	0.954
		Munesa (N = 108)	1.50	0.140ns	0.072	0.209
		Lemu Bilbillo (N = 107)	1.56	0.09ns	0.072	0.690
Knowledge about the insect pest of field pea	Cheliya (N = 86, Mean = 1.69)	Liben Jawi (N = 85)	1.72	-0.032*	0.071	0.971
		Munesa (N = 108)	1.69	0.00*	0.067	1.000
		Lemu Bilbillo (N = 107)	1.65	.032*	0.068	0.965
Pest management methods	Cheliya (N = 86, Mean = 1.76)	Liben Jawi (N = 85)	1.76	0.00*	0.076	0.999
		Munesa (N = 108)	1.64	0.12ns	0.071	0.359
		Lemu Bilbillo (N = 107)	1.77	-0.01*	0.072	0.999
Storage types	Cheliya (N = 86, Mean = 1.88)	Liben Jawi (N = 85)	1.86	0.02*	0.053	0.966
		Munesa (N = 108)	1.89	-0.01*	0.050	1.000
		Lemu Bilbillo (N = 107)	1.81	0.07ns	0.050	0.497

S.E. =Standard Error; I, J = multiple comparison of district one (I) with other districts (J),N = number of households

As shown in Table 6, the chi-square test shows there was significant difference among study districts on the source of seed.All of the households used their own seed in both Cheliya and Liben Jawi districts. In Munesa 87% households used their own seed whereas the households who got seed from other farmer, seed enterprise and bureau of agriculture comprised 13%. In Lemu Bilbillo only few farmers (1.9%) used seed enterprises as seed source whereas the majority of the farmers (981%) used their own seed. There was non-significant difference among the study areas on the responses given to the knowledge of pests of field pea generally and insect pests of the crop particularly. The majority of the households, 64% in Cheliya and 60% in Liben Jawi did not have knowledge on field pea pests. Though 31.4% and 28.2% responded as they know field pea insect pests in Cheliya and Liben Jawi districts, respectively, none of the households knew *B. pisorum*. This agrees with Gebreegziabher and Tsegay (2018) that in spite of the crop's popularity beside many farmers, the production constrains of the crop such as pests and high yielding varieties are still need awareness. There was significant difference among study areas on pest management practices. There was non-significant difference on type storages used among all study areas. The popular grain storage types in all districts were sack and bin.The sack storage was the one mainly used to store grains in all study areas (Table 6).

Table 6. Determinants of farmers' practices and knowledge of B. pisorum attack on field pea in study districts (Cheliya, Liben Jawi, Munesa and Lemu Bilbillo)

Variables	Districts								χ2-value	P-value
	Cheliya (N = 86)		Liben Jawi (N = 85)		Munesa (N = 108)		Lemu Bilbillo (N = 107)			
	Frequency	%	Frequency	%	Frequency	%	Frequency	%		
Seed source										
Own	86	100	85	100	94	87	105	98.1	32.23*	0.00
another farmer	0	0	0	0	5	4.6	0	0		
Market	0	0	0	0	0	0	0	0		
Seed enterprise	0	0	0	0	5	4.6	2	1.9		
Bureau of agriculture	0	0	0	0	4	3.7	0	0		
Knowledge about the general pests of field pea										
Yes	31	36	34	40	54	50	47	43.9	4.205^{ns}	0.24
No	55	64	51	60	54	50	60	56.1		
Knowledge about the insect pest of field pea										
Yes	27	31.4	24	28.2	34	31.5	37	34.6	$.887^{ns}$	0.829
No	59	68.6	61	71.8	74	68.5	70	65.4		
Pest management methods										
Yes	21	24.4	20	23.5	39	36.1	31	28.97	12.72*	0.048
No	65	75.6	65	76.5	69	63.9	73	71.03		
Storage types										
Bin	10	11.6	12	14.1	12	11.1	20	18.7	3.11^{ns}	0.375
Sack	76	88.4	73	85.9	96	88.9	87	81.3		
Underground	0	0	0	0	0	0	0	0		
Plain ground	0	0	0	0	0	0	0	0		

Key: * = significant, ns = not significant at 5% probability level, N = number of households

In all study districts of the two zones, there were two commonly usedstorage types: bin and sack. These storage types were among different storage systems reported in Ethiopia (Tadesse *et al.*, 2006). In Cheliya district of West Shewa, about 18.52% of the farmers used bin while about 22.89% used sack as storage type. In Liben Jawi of the same zone, bin and sack stores were common, where both storage types equally shared 21.99%. In both districts of East Arsi zone, bin and sack stores were widely used to store pulse grains. In Munesa and Lemu Bilbillo bin stores shared 22.22 and 37.04%, respectively while sack stores shared 28.92 and 26.20% respectively (Fig 3). The selection of storage types by the farmers were based on the purpose of grains stored; those which were sold soon after harvest mainly stored in sacks while which were intended to stay long in bin. The current result indicated bin and sack stores as the dominant grain stores used in all the study areas.

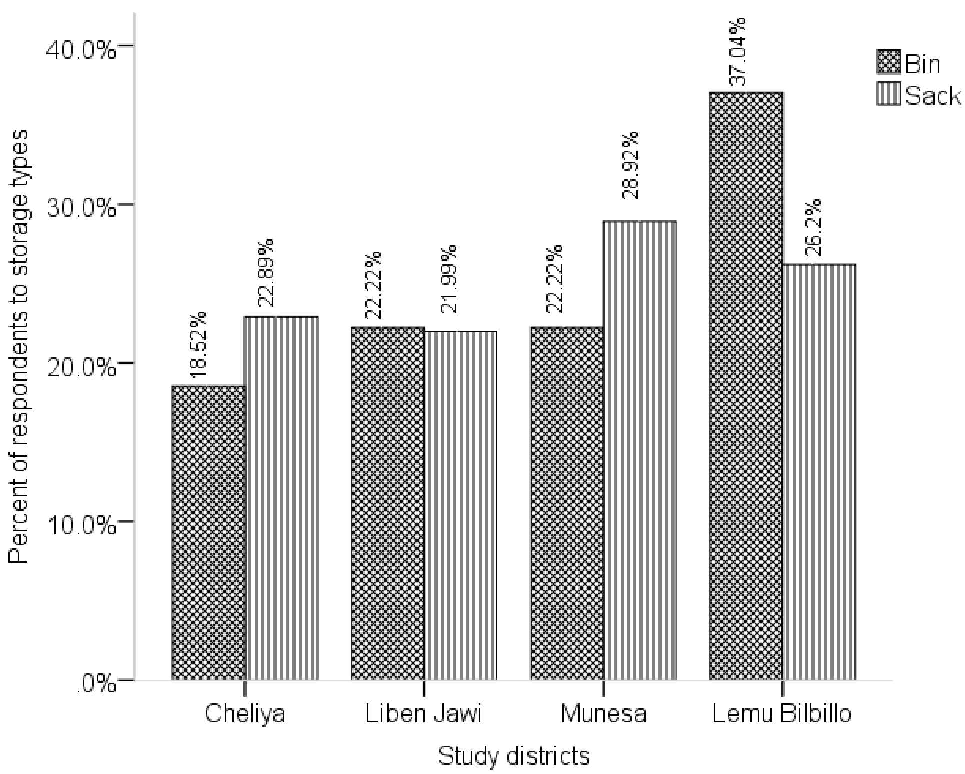

Figure 3. Percentage of respondents to storage types in study districts.

4.1.3. Post-harvest grain losses due *B. pisorum*

There were grain damage and grain weight losses in all districts exceptLemu Bilbillo. Percent grain damage recorded ranged from 0 to2.11. Grain damage and grain weight loss recorded in Munesa district was significant to Cheliya, Liben Jawi and Lemu Bilbillo districts (Table 7).

Table 7. Percent grain damage and grain weight loss due to *B. pisorum* in the study areas at district level

Zone	Districts	Percent grain damage Mean (95% CI)	Grain weight loss Mean (95% CI)
West Shewa	Cheliya	0.01 (-0.28391, 0.30461) a	0.01 (-0.15952, 0.18324) a
	Liben Jawi	0.09 (-0.2035, 0.3885) a	0.01 (-0.17647, 0.19813) a
East Arsi	Munesa	2.11 (1.847, 2.379) b	1.19 (1.040, 1.350) b
	Lemu Bilbillo	0 (-0.260187, 0.260187) a	0 (-0.151533, 0.151533) a

Means with the same letter within column are non-significant at Significance level α = 0.05, Least significance difference.

4.2. Ovicidal effect of Insecticideson*B. pisorum* eggs

There was non-significant difference (P>0.05) on eggs recorded both before and after treatment application (Table 8). Even though statistically non-significant, there was a clear reduction of egg counts after treatment application. The result of this finding disagrees with the finding of Seidenglanz *et al.* (2011). This might has happened because of the coincided with the phenology of the pea plant that it is indeterminate in its growth habit and evolvement of new upper nodes which usually favors further oviposition for the female adults. As such the number of died eggs might be compensated by the newly oviposited eggs and, egg numbers before and after treatment application probably balances each other. Position of eggs on the pods in relation to the direction of spraying and eggs which might be laid after spraying the insecticides could also influence the egg numbers. The form in which the eggs of *B. pisorum* laid might also have its influence on the efficiency of the treatments as the eggs of the insect usually laid in the form of clusters than single eggs in which only the upper top eggs face treatments and the bottom eggs rarely affected by the applied insecticides (Seidenglanz *et al*., 2007).

4.3. Larvicidal effect of Insecticides on larvae of *B. pisorum*

There was non-significant difference (P>0.05) among treatments as compared to control plots on number of larvae counted per 50 seeds (Table 8).Even though it is not totally possible to conclude that the larvae mortality as well as egg mortality was exactly the direct effect of the insecticides, Sevin at flowering stage showed highest larvicidal effect as compared to the rest of the treatments. The death of larvae might be the consequence of the previous insecticidal effect on eggs too.

4.4. Effect of Insecticides on adult *B. pisorum*

There was no significant difference (P>0.05) on the number of adult *B. pisorum* emergence per 50 g seeds. This might be because of competition that led to many larvae death. Aznar-Fernandez *et al*. (2018) and Afonin *et al*. (2008) have described that as many as 45 eggs can be laid per single pod and usually about 5 larvae can get into one grain even though usually only one larvae develops and pupate while the others perish either because of physical damage during exit or due to foodcompetition. So, with such phenomena and the larvicidal effects of the insecticides, the number of emerged adult *B. pisorum* became minimal and didn't show significant differences among treatments.

4.5. The effects of sprayed Insecticides on thousand seed weight and yield

The treatments were not significantly different (P>0.05) from one another when 1000 seeds' weight was considered after drying the seeds to their standard moisture content (Table 8). This might be because the seeds were from the same variety. There was non-significant difference on yield parameter. None of the applied treatments affected the yield that would be harvested from each plot. This was because *B. pisorum* attacks seeds of growing pea crop, but not dried or stored seeds. The larvae and/or pupating adult inflicts losses in crop yield and quality by consuming the seed and as such, the effect of *B. pisorum* on yield is more related to losses in store than direct yield loss at harvest.

Table 8. Mean reaction of *B. pisorum* to insecticides (treatments) under study for egg count, larvae/50 seeds, number of adults, thousand seed weight, and yield variables

Treatments	Egg counts		Larvae/ 50 seeds** Mean ± SE	No. of Adults/50 g seeds** Mean ± SE	Thousand seed weight (g) Mean ± SE	Yield (Qt./ha) Mean ± SE
	Before spray eggs/pods Mean ± SE	After spray eggs/pods Mean ± SE				
K (F)	4.50 ± 0.17	2.03 ± 0.1	5.5 (2.28 ± 0.09)	2.25 (1.54 ± 0.08)	308.77 ± 2.08	41.45 ± 1.74
K (P)	4.58 ± 0.14	2.10 ± 0.09	4.25 (1.92 ± 0.2)	3 (1.75 ± 0.17)	291.27 ± 7.81	37.18 ± 2.13
K (F+P)	3.83 ± 0.22	1.58 ± 0.13	2.25 (1.61 ± 0.17)	4 (1.94 ± 0.09)	298.52 ± 6.40	42.63 ±1.23
C(F)	4.53 ± 0.14	1.85 ± 0.05	2.25 (1.61 ± 0.08)	1.25 (1.26 ± 0.18)	296.74 ± 0.86	36.05 ± 1.56
C (P)	3.98 ± 0.16	1.65 ± 0.07	3.5 (1.88 ± 0.09)	1.75 (1.41 ± 0.11)	268.34 ± 6.19	40.6 ± 1.53
C (F+P)	4.65 ± 0.28	2.03 ± 0.16	7 (2.61 ± 0.12)	3.25 (1.88 ± 0.07)	278.42 ± 5.42	42.96 ± 1.39
S (F)	5 ± 0.13	2.30 ± 0.05	1.5 (1.35 ± 0.18)	4 (1.98 ± 0.1)	285.74 ± 2.55	45.72 ± 1.79
S (P)	4.78 ± 0.21	2.23 ± 0.1	9.25 (2.98 ± 0.17)	2 (1.48 ± 0.15)	281.67 ± 5.37	35.96 ± 0.63
S (F+P)	4.63 ± 0.22	2.13 ± 0.09	7.5 (2.56 ± 0.06)	4.25 (1.96 ± 0.08)	271.5 ± 1.79	38.93 ± 0.57
Unsprayed plot	5 ± 0.24	2.30 ± 0.09	4.75 (2.14 ± 0.06)	4 (2.06 ± 0.08)	295.07 ± 2.14	45.41 ± 1.24
LSD (0.05)	1.22ns	0.77ns	1.33ns	1.07ns	42.60ns	9.74ns
CV	18.42	26.34	43.76	42.83	10.21	16.5

**=Square root transformed; means within brackets are after data transformation. Means followed by the same letters within columns are non-significant at 5% Least Significant Difference (LSD) and, the results are presented using untransformed data. KF=Karate at flowering, KP=Karate at pod setting, K(F+P)=Karate at both flowering & pod setting stages, CF=Coragen at flowering, CP=Coragen at pod setting, C(F+P)=Coragen at both flowering & pod setting stages, SF=Sevin at flowering, SP=Sevin at pod setting, S(F+P)=Sevin at both flowering & pod setting stages.

4.6. Effect of spraying insecticides on percent grain damage, grain weight loss and germinationpotential of field pea

There were no significant percent grain damage and grain weight losses foundamong the treatments (Table 9). Minimum percent grain damage and grain weight loss values were found and this was because the insecticides inhibited the pupation of larvae because of their larvicidal effects. The result agrees with the studies of Smith (1990) which states that grain weight loss usually became below 4% when the Pea weevil is managed by spraying insecticides.

The result from germination test showed non-significant difference. However, because percent germination of greater than 80 was recorded in all treatments including control plot, the result indicated that the insecticides had no detrimental effect on the viability of the seeds. This result agrees with Matthews and Holding (2005).

4.7. The effect of spraying insecticides on days to adult emergence and theirovicidal effectiveness

There wasnon-significant difference ($P>0.05$) on the number of days to adult emergence. The shortest days (40.85 ± 2.03) to adult emergence was record fromSevin application at flowering stage while the longest days (62.7 ± 1.26) was recorded on spraying Sevin at pod setting stage (Table 9). Applying Coragen at flowering stage and Sevin at pod stage performed best in delaying the number of days to adult emergence.

The efficiency of the treatments ranged from 50.08% to 66.59%. Spraying Coragen at flowering stage showed highest efficiency (66.59%) as compared to others followed by applying Sevin at pod setting stage (64.01%). None of the insecticides were found to be toxic to the crop, i.e., no symptom of phytotoxicity observed.

Table 9. Effect of Insecticides, under field conditions, on percentage grain damage (%), grain weight loss (%), germination test, adult emergency and eggs

Treatments	Percent grain damage (%) **	Grain weight loss (%) **	Germination test (%) **	Days to adult Emergency	Efficacy of treatments on egg (% E)
K (F)	0.76 (1.09 ± 0.03)	0.1 (0.77 ± 0.02)	89 (94.26 ± 0.64)	50.63 ± 2.68	61.44
K (P)	0.85 (1.1 ± 0.12)	0.21 (0.83 ± 0.03)	91 (95.31 ± 0.88)	44.18 ± 2.35	50.08
K (F+P)	1.83 (1.38 ± 0.05)	0.47 (0.95 ± 0.01)	88 (93.76 ± 0.28)	53.2 ± 2.12	53.60
C(F)	0.47 (0.97 ± 0.12)	0.16 (0.81 ± 0.04)	85 (92.17 ± 0.79)	62.28 ± 0.62	66.59
C (P)	0.45 (0.95 ± 0.06)	0.14 (0.8 ± 0.01)	90 (94.84 ± 0.43)	52.15 ± 2.75	52.12
C (F+P)	0.99 (1.18 ± 0.05)	0.22 (0.84 ± 0.01)	84 (91.64 ± 0.62)	47.73 ±1.83	56.32
S (F)	1.24 (1.27 ± 0.08)	0.17 (0.82 ± 0.01)	81 (89.99 ± 0.2)	40.85 ± 2.03	58.22
S (P)	0.56 (0.95 ± 0.07)	0.09 (0.76 ± 0.02)	89 (94.3 ± 0.58)	62.7 ± 1.26	64.01
S (F+P)	1.95 (1.45 ±0.04)	0.34 (0.9 ± 0.01)	91 (95.31 ± 0.43)	55.65 ±3.14	53.33
Unsprayed plot	1.18 (1.24 ± 0.05)	0.22 (0.85 ± 0.02)	85 (92.18 ± 0.58)	50.5 ± 2.66	0.00
LSD (0.05)	0.66ns	0.20ns	4.75ns	21.76ns	-
CV (%)	39.11	17.03	3.5	28.85	-

**=Square root transformed; means within brackets are after data transformation. Means followed by the same letters within columns are non-significant at 5% Least Significant Difference (LSD) and, the results are presented on means of untransformed data. KF=Karate at flowering, KP=Karate at pod setting, K(F+P)=Karate at both flowering & pod setting stages, CF=Coragen at flowering, CP=Coragen at pod setting, C(F+P)=Coragen at both flowering & pod setting stages, SF=Sevin at flowering, SP=Sevin at pod setting, S(F+P)=Sevin at both flowering & pod setting stages

5. SUMMARY AND CONCLUSIONS

Field pea is one of the most important pulse crops in the cool highlands of Ethiopia forming an integral part of the daily diet of the society along with other cereals and pulses. However, the production of this crop is hampered by several biotic and a biotic factor. Insect pests are one of the major constraints of field pea production, among which*B. pisorum*is an economically important insect pest.

The present study assessed farmers' knowledge about *B. pisorum* and their practices for the target pest management. Accordingly, the study revealed that farmers did not have much information about the insect and associated damage. Although it's a one season assessment report, *B. pisorum*was found in all surveyed districts except Lemu Bilbillo. This indicated that the insect spreading to field pea producing parts of the country where it was not reported earlier. However, the damage level and grain weight losses due to *B. pisorum*were very low across the study areas.

The present study also investigated the effectiveness of three insecticides with different times of application to manage the pest in the field. Even though all the treatments and control plot were statistically no-significant, the results of this study showed that application of Sevinand Coragen at flowering stage performed best in terms of their larvicidal activities.

Generally, because of the limited information on *B. pisorum*among the field pea producing farmers in Ethiopia, many farmers did not know the problem of *B. pisorum*. However, contrary to this, *B. pisorum* was recorded in three districts except one. Despite the minimum records on percent grain damage and grain weight losses from both survey and field experiments, this insect needs greater awareness creation to limit its current distribution in Ethiopia. Two or more seasons study can bring a better result as the result from both survey and field study was from one season study. Above all, screening a greater number of insecticides under different locations will improve the limitations of the current study.

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APPENDICES

Appendix table 1. Questionnaires used to collect primary data

Name of the Interviewer: ___________________________________Date__________________

Zone __________________Woreda/district_________________Kebele_____________________

1. Farmer name____
2. Variety____
3. Where did you get the seed?

a. Own it myself ☐ b. From other farmer ☐ c. Market ☐ d. Seed enterprise/farmers' association ☐

4. Do you any problems (diseases/insects, etc.) on this crop when it is in the field or after harvest? Yes ☐ No ☐

If Yes for Q#4, Is it disease? Insects?Other?
Specify____

If Insect, do you know its name? Yes ☐ No ☐

If yes, what you call it locally? ____________________________________

5. Do you know any field pea insect pest? Yes ☐ No ☐

a. If Yes, what you call it____
b. How it affects your seed____
c. When it starts/time?

In the field ☐ At flowering ☐ At maturity ☐ At harvesting ☐ In the storage ☐

6. How frequently is your crop being affected by Pea weevil?

a. Once per season ☐ b. Twice per season ☐ c. More than two ☐ d. Do not know ☐

7. Pest Management methods a. Insecticides Yes ☐ No ☐

If Yes,

Where did you get it? ____

What (name) of the insecticide ____

When do you apply? ____

What (is it liquid, dust, gas etc.) the insecticide? ______________________________

How much of this insecticide you use per hectare? ______________________________

How long you stay to consume/sell the grains? _________________________________

b. Weeding ☐ c. Early/late planting ☐ d. Early/late harvesting ☐

8. How frequently do you use insecticides in your farm?

a. Once per season ☐ b. Twice per season ☐ c. More than two ☐ d. Do not apply ☐

9. Storage methods

a. Bin ☐ b. Sack ☐ c. Underground ☐ d. Plain ground ☐

Appendix table 2. Number of households and sample size of field pea producer in selected PAs and the study districts

Districts (Woredas)	Peasant associations (Kebeles)	Total number of households producing field pea	Number of sampled households of field pea producers
Cheliya	Jarso Dire Geda	650	23
	Beda Ilamu	555	19
	Refisso Alenga	720	25
	Wegidi	540	19
Liben Jawi	Mugno Keshembel	753	26
	Mugno Babullo	710	25
	Roge Ajjo	337	12
	Roge Danissa	625	22
Munesa	Copa	739	26
	Doba Ashie	700	25
	Kersa Anno	687	24
	Gerembota Lole	934	33
Lemu Bilbillo	Lemu Dimma	719	25
	Dawa Bursa	693	24
	Bekoji Negesso	810	28
	Cipa Michaela	872	30
Total		11044	386

Appendix table 3. Mean squares for the variables collected from field experiment

Variables	Mean Squares			Mean	CV (%)
	Rep, df=3	Treatment, df=9	Error, df=27		
Ecbsrs	10.035*	0.5915ns	0.701	4.55	18.42
Ecasrs	1.558*	0.258ns	0.282	2.02	26.34
L/50 g seed	1.128ns	1.074ns	0.839	2.09	43.76
A/50 g seed	0.774ns	0.321ns	0.546	1.73	42.83
TSW	613.097ns	654.705ns	862.286	287.60	10.21
Yld	342.641*	51.729ns	45.063	40.69	16.50
PGD	0.291ns	0.131ns	0.204	1.16	39.11
GWL	0.036ns	0.013ns	0.020	0.83	17.03
GT	12.606ns	12.784ns	10.69	93.38	3.50
DAE	47.378ns	196.807ns	225.00	51.99	28.85

*=Significant at 5% level, ns=non-significant, Ecbsrs = Egg counts before second round spray, Ecasrs = Egg counts after second round spray, L=Larvae, A=Adults, Yld=Yield, PGD=Percent grain damage, GWL=Grain weight loss, DAE= Days to adult emergence, GT=Germination test, KF=Karate at flowering, KP=Karate at pod setting, K(F+P)=Karate at both flowering & pod setting stages, CF=Coragen at flowering, CP=Coragen at pod setting, C(F+P)=Coragen at both flowering & pod setting stages, SF=Sevin at flowering, SP=Sevin at pod setting, S(F+P)=Sevin at both flowering & pod setting stages.

Appendix table 4. Weather data of study area, HARC, during 2017

Months	RF (mm)	Air Temperature (°C)			RH (%)
		min	max	average	
January	0	-0.6	25.2	12.3	36
February	30.2	5.2	25.6	15.4	39

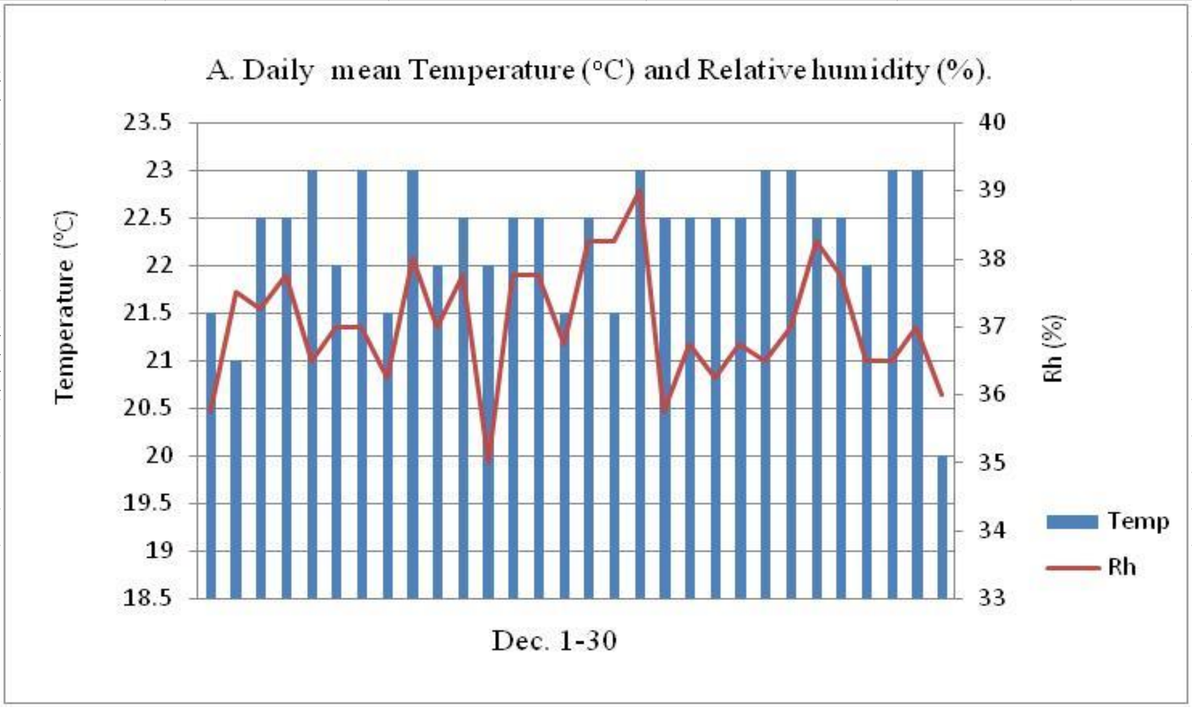
March	24	8.2	26.3	17.25	47
April	56	8.8	26.2	17.5	53
May	129.6	10	23.5	16.75	69
June	74.6	8.8	24.2	16.5	77
July	172.8	8.8	22.1	15.45	83
August	311.4	10.4	21.7	16.05	76
September	244	8.3	22.6	15.45	71
October	29	7.8	24.2	16	61
November	0	2.8	24	13.4	46
December	0	0.6	23.9	12.25	47
Mean	89.3	6.6	24.1	15.35	58.8

Districts	Major crops of produced	Major production problems (abiotic problems)	Soil type	Mean annual rainfall (mm)	Mean annual temperature (oC)
Cheliya	- Wheat	- rust	- red to black	950	18 - 28
	- Teff	-			
	- Barley	- leaf blotch			
	- Maize	- stalk borer, MLND			
	- Faba bean	- wilt (rarely), pod borer			
	- Field pea	- pod borer			
	- Noug/Niger	-			
	- Sesame	-			
	- Cabbage	- aphids			
Liben Jawi	- Teff	-	- light to heavy black	1000	15 - 25

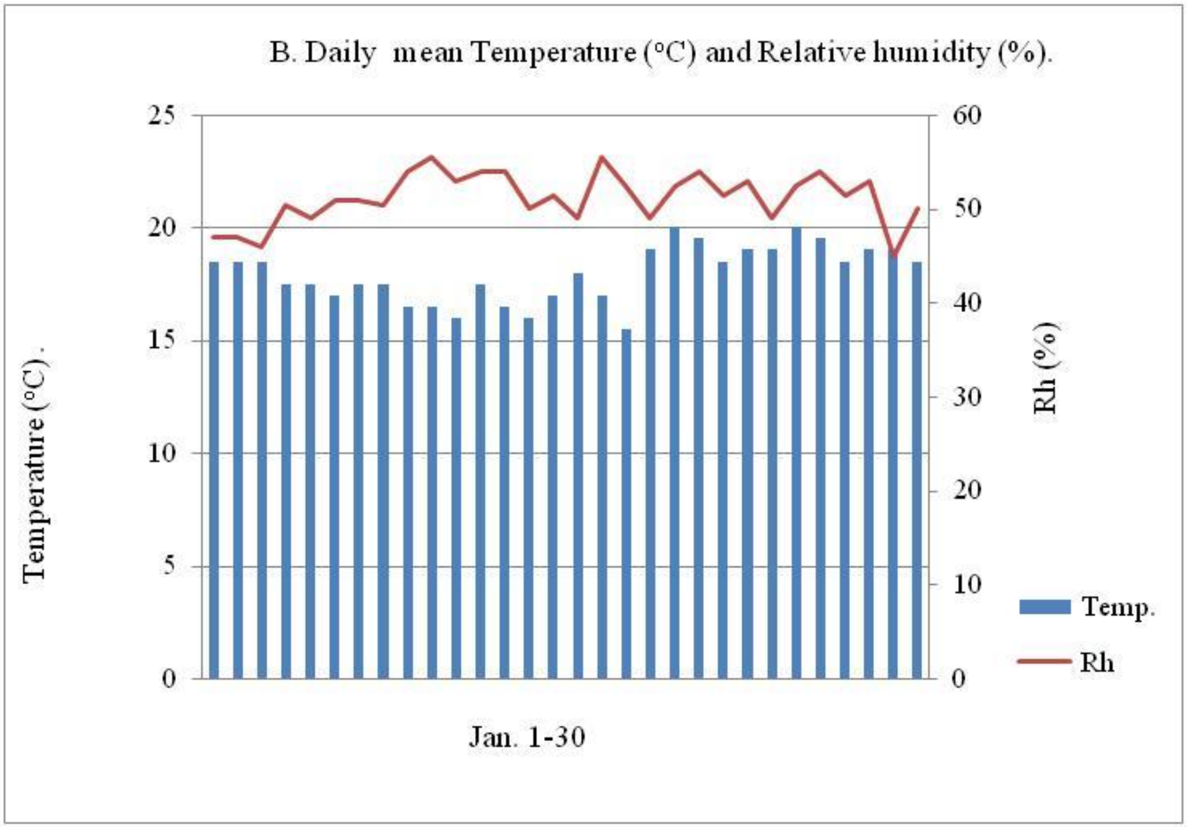
Source: Holetta Agro-metrology station, 2017.

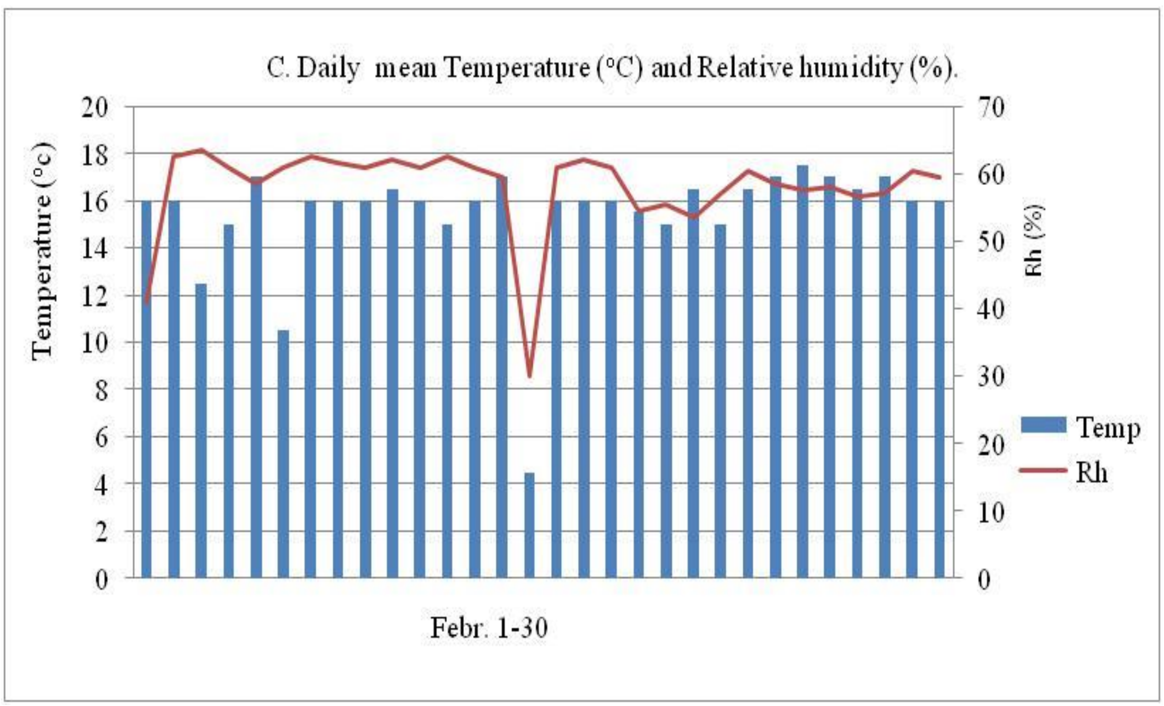
Appendix table 5. Agro-ecological information in the survey areas

	- Wheat	- rust			
	- Barley	- leaf blotch			
	- Maize	- yellowing and stunting			
	- Faba bean	- spot, pod borer			



Appendix figure 1. Temperature (°C) and relative humidity (%) in the laboratory at HARC during experimental period (from December to February, 2017/2018)


B. Daily mean Temperature (°C) and Relative humidity (%).
25
20
15
10
5
0
60
50
40
30
20
10
0
Temperature (°C) .
Rh (%)
Temp.
Rh
Jan. 1-30


C. Daily mean Temperature (°C) and Relative humidity (%).
20
18
16
14
12
10
8
6
4
2
0
70
60
50
40
30
20
10
0
Temperature (°c)
Rh (%)
Temp
Rh
Febr. 1-30