Studies on the status of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) and its natural enemies, and the effect of botanicals and cow urine against the pest and natural enemies

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Dedication

To my family, my wife w/o Sofia Kassaw Teshome and our children Fuad, Aziz and Aymen

Abbreviations/Acronomys

ICIPE	International Centre of Insect Physiology and Ecology
AATF	African Agricultural Technology Foundation
CACC	Central Agricultural Census Commission
NIAB	Nuclear Institute for Agriculture and Biology
GPS	Global Positioning System
EPAR	Evans School Policy Analysis and Research
CSA	Central Statstical Authority
SPSS	Statistical Package for the Social Scences
KPHCL	Kombolcha Plant Health Clinic Laboratory
ISU	Iowa State University
GRDC	Grain Research and Development Corporation
CABI	CAB International
EOLSS	Encyclopoda of Life Support System
KNUST	Kwame Nkrumah University of Science and Technology
EWC/UH	University of Hawaii

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Abstracts

The exotic stemborer, Chilo partellus (Swinhoe) (Lepidoptera: Crambidae) is the most important pest of sorghum in East Africa. The insect infests sorghum crop throughout its growth stages. It has also been recorded and documented from wild host plants. C. partellus has several native and exotic natural enemies. Field and laboratory studies were conducted to know the status of C. partellus and its natural enemies and assess the efficacy of botanicals and cow urine against C. partellus and their effect on the natural enemies. Surveys were conducted in 2016/17 and 2017/18 in three districts and nine farmer fields of Kalu, Bati and Dawa Chefa districts, Ethiopia. Sampling was done both randomly and purposively. Analysis of variance (ANOVA) was carried out to determine if there were any significant differences across the locations and between the plant growth stages. Laboratory evalution of plant and animal-based insecticides and optimum concentration on C. partellus was conducted in 2016. The experiment was laid out in completely randomized design in three replications for each rate. The rates were 2g, 2.5g, 3g of powder and 1ml, 1.5ml and 2ml w/v of the solutions. The most effective biopesticides were further tested in 2017 in farmer's field. The trial was designed in a randomized complete block design in factorial arangment in three replications. The treatments were at two levels of frequencies (2 & 3 times application) and three rates of powder (1g, 2g and 3g) and three rates of solution (5%, 10% and 15%). The study revealed that C. partellus constituted 90.3 & 91.2% on sorghum and 45.4 & 69.2% on wild hosts in 2016/17 and 2017/18, respectively. Significant differences were observed among the host plants and sorghum growth stages. In sorghum, C. partellus density were found to be significantly higher than on wild hosts ($P<0.05$). Relatively higher numbers of larvae (5.02±0.5) per plant were recorded from Bati at seedling stage and the lowest; (3.32±0.3) was from Kalu. Significant difference was observed in incidence of C. partellus ($F=11.8$; $d.f.=2$;$P<0.008$). C. partellus was significantly ($F=60.3$;$d.f.=2$; $P<0.000$) different at the three plant growth stages across the locations. Similarly, significant ($F=24.75$; $d.f.=2$;$P<0.001$) difference was recorded at vegetative stage in terms of exit holes. Natural enemies' abundance showed significant difference among sorghum growth stages. C. flavipes (Cameron) recorded abundantly at maturity stages of sorghum. The highest number (0.48) was recorded from Bati at the

maturity stage with the relative abundance of 33.8%. Cotesia flavipes parasitism varied across the locations and host growth stages. The highest (61.5%) parasitism was recorded from Bati at maturity in both seasons. Ants were highly abundant at maturity and lower at early stages at Bati, while (83.7%) relative abundance was recorded from Kalu. Earwigs were highly abundant in Dawa Chefa district, while the maximum number was found from Bati at maturity stage with the relative abundance of 26.3%. Laboratory study showed that Millettia ferruginea seed powder and aqua extract caused 100% mortality at the highest rates after 24 hrs exposure. Cow urine, Phytolacca dodecandra aqua extract and its mixture with cow urine were found effective. Results of field trial showed that all pesticides formulations significantly (P<0.01) reduced C. partellus damage at the highest rates with two times applications compared to untreated check. Likewise, their effect on the main natural enemy of C. partellus was minimal. C. partellus was found attacking by several natural enemies at each stages of sorghum, thus it is suggested that use of plant and animal-based insecticide can be regarded as suitable alternative to synthetic insecticides for the management of C. partellus in the field.

Key words: Status, Abundance, Infestation, Sorghum, Biopesticides, *C. partellus*

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Chapter 1

General Introduction

1.1 Background of the study

Sorghum (*Sorghum bicolor* L. Moench) is a major food and nutritional security crop to more than 100 millions people in Eastern horn of Africa (Gudu *et al*., 2013; Yoseph Tekle & Zemach Sorsa, 2014)**.** In Ethiopia, sorghum is the third most important food grain after teff and maize, produced mainly for food consumption (CSA, 2005; FAO, 2009; IITA, 2009; Schneider & Anderson, 2010). Currently more than 5 million households grow this crop (EIAR, 2014; Belay Fentaye & Hintsa Meresa, 2017) to meet needs for food, income and construction. The main use of sorghum in Ethiopia is for producing injera. But it has also incredible uses for the farmers and no part of this plant is ignored. The stalks are used for animal feed, mulching, fuel and house construction. The grain is also used for the preparation of other traditional foods and beverages such as tella and areki. It is also consumed boiled and roasted (Stone *et al*., 2011; FAO, 2014 & EIAR, 2014).

The crop possesses great genetic diversity and is grown across varied agro-ecological zones of the country (Kinfe Hailegebriel & Adane Tesfaye, 2018) and it covers 14.4% (about 1.6 million hectare) of the land allocated for cereals (CSA, 2012). Kalu, Bati and Dawa Chefa districts in South Wollo and Oromia zones of Amhara National Regional State are among the major sorghum growing regions in Ethiopia. Farmers in these regions are highly dependant on this crop since the areas receive little rainfall which as a result is arid. Despite the diversity, uses and the wide range of environment in which the crop

grows, yields are usually low in Ethiopia because of several factors including lepdopterean cereal stem borers (Emana Getu *et al*., 2008; Wortmann *et al*., 2009 & Sylvain *et al*., 2015).

Among these, the exotic *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) is the most injurious in the region. *C. partellus* is a medium sized moth; the larvae are the destructive stage and damage all the growing stages of sorghum. Leaf scraping, stem boring and total death of young plants (dead heart) are some of the damage caused by this pest on sorghum resulting significant yield loss (Tadele Tefera, 2004; Emana Getu *et al*., 2008; GRDC, 2009 & Kinfe Hailegebriel & Adane Tesfaye, 2018).

Farmers in the region usually used chemicals in controlling this pest as it is most effective and convenient. However synthetic insecticides can pose several problems to the environment. Naturally occurring biological control agents have a potential role in the management of this pest in fields of sorghum. So, considering their impact on the population reduction of this pest is necessary. Thus, *C. partellus* control practice that are effective and economically feasible, nontoxic to the environment and less risky to natural enemies need to be made accessible to farmers. Accordingly, knowledge on *C. partellus* and natural enemies' status is crucial to plan and manage the pest and non target insects effectively in the natural environment. However, there were no or only few studies conducted on the current status of this pest, its natural enemies and management practices in the target areas. Thus, these studies were initiated and conducted with the following objectives:

1.2 Objectives

1.2.1 General objective

To identify the status of *C. partellus* and its natural enemies on sorghum and wild hosts and its damage levels on different stages of sorghum and evaluate the efficacy of plants and animal-based insecticides to develop effective management of the insect

1.2.2 Specific objectives

1. To determine the abundance and infestation levels of *C. partellus* on different growth stages of sorghum and wild host plants
2. To assess the abundance and impacts of natural enemies on all stages of sorghum crops
3. To evaluate the efficacy of some botanicals and cow urine against *C. partellus* under laboratory condition
4. To screen and test the best treatments for the control of *C. partellus* on farmers' field of sorghum

Chapter 2

Literature Review

2.1 Overview of Sorghum

Sorghum is classified under the family Poaceae (grass family), genus sorghum and species bicolor (Stapf, 1917; Kinfe Hailegebriel & Adane Tesfaye, 2018). Sorghum is herbaceous annual, highly diversified, and follows the C4 photosynthetic pathway like maize thus has greater efficiency of dry matter production relative to water use (Charles *et al*., 2006). Roots are fibrous and can extend from the top 90cm soil layer to twice that depth. The stem shows the greatest differences between genotypes, ranging from thin to thick, with low or multiple tillering. Stems are erect, measures 0.6m to 5m high and 5mm to 30mm in diameter. Leaves are broad, smooth, very similar to maize leaves, but shorter and broader. Inflorescence is a panicle, around 60cm long, bearing up to 6000 spikelets (Rattunde *et al*., 2001; Balole & Legwaila, 2006).

Sorghum is cultivated in wide geographic areas with erratic, poor rains and soils. The optimal growth conditions are 25-30°C temperature with less than 400-750mm annual rainfall, well-drained loamy clay soil with a pH between 5.5 and 7.5 (Balole & Legwaila, 2006). It can also withstand water logging from heavy rain and hence can grow in both temperate and tropical zones. Forage sorghum is important substitute for more water-consuming crops in environments where water is limited, due to drought. Owing to its inherent nature to withstand drought and temperature, it is a potential crop for combating climate change and will be the crop of the future. For that reason, the crop will be

extremely valuable wherever water becomes short because of global climate change (Brouk *et al*., 2011 & Contreras-Govea *et al*., 2010).

Sorghum production varies across the different parts of the world. According to FAO report, United States of America is the top sorghum producer with a harvest of 9.7 million tonnes followed by India, Nigeria, Sudan, and Ethiopia among others (FAOSTAT, 2011). In Africa the most important sorghum producers are Nigeria, Ethiopia, Sudan, Burkina Faso, Tanzania and Niger in that order (Emana Getu *et al*., 2001; 2002 & FAO, 2014). In these countries the crop is an important mainstay for most of food insecured people. In eastern Africa, sorghum is not only the major food but also nutritional security crop to more than 100 million people, due to its resilience to drought and other production constrains (Wortmann *et al*., 2009 & FAO, 2010).

Sorghum is the fifth most important staple food crop after wheat, rice, maize and barley in the world and second after maize in Africa (FAO, 2010 & Stone *et al*., 2011). Moreover, the crop is versatile enough used for alcoholic beverage and syrup production. The stalks are used for animal feed, fuel, mulching and fence construction. Nutritionally, sorghum is an excellent source of riboflavin, Vitamin B6, thiamin and minerals such as iron, potassium, manganese and magnesium. It possesses huge amount of carbohydrates with 40.78% protein, 18.97% fat, 2.50% calcium and iron, vitamin B1, and nicotinic acid in small amounts. Sorghum assists in digestion, prevents cancer, controls diabetes, helps celiac disease, maintains bone health, prevents anemia, boosts level of energy, assist in thyroid prevention and increases conscious mental activities (FAO, 2014).

2.2 Sorghum in Ethiopia

Sorghum is native to east Africa, probably Ethiopia (Hariprassana, 2017). Several studies suggested that it was domesticated and originated in the northeast quadrat of Africa, most likely in the Ethiopian-Sudan border regions. The presence of wild and cultivated sorghums in Ethiopia reveals that the country is the primary centre of its origin and diversity as well (Mekibeb, 2009; Kinfe Hailegebriel & Adane Tesfaye, 2018). Though Ethiopia is the centre of its origin and diversity (FAO, 2010 & 2012) it ranks 6th globally and the 2nd largest producer in Africa next to Nigeria (FAOSTAT, 2011 & Wani *et al*., 2011).

In Ethiopia, sorghum is the third most important food grain after teff and maize and produced mainly for food consumption (CSA, 2005 & 2012). The lives of millions of poor Ethiopians depend on sorghum. Besides it has tremendous uses for the farmers. Villagers prepare a wide range of traditional fermented foods and beverages from sorghum grains. Some of these include *injera*, *dabo, kita, porridge*, *nefro, bulla, alcoholic beverages such as tella, areki, borde, keribo, and bukrie.* These foods are relatively cheap to prepare and are therefore important alternatives for low income consumers who cannot afford industrially processed foods and beverages. Most of the customs and rituals of Ethiopian traditional fermented foods and beverages exist still now in urban and rural households. Sorghum stover (stalks and leaves) are important source of animal fodder, cooking fuel and house construction. In Ethiopia, stover accounts for 37% of the crop value compared to Sub Saharan Africa where it accounts for only 26% of the total crop value (Wortmann *et al*., 2009 & FAO, 2010).

In Ethiopia sorghum is grown in almost all regions occupying an estimated total land area of 1.6 million hactare (CSA, 2012). This crop is grown in almost all regions, from 400-2500m and in drought prone areas of the country (FAO, 2010 & CSA, 2012). Oromia, Amhara and Tigray regions are the major production regions which represent about 78% of sorghum among small holder farmers (IITA, 2009; FAO, 2010 & CSA, 2012). Sorghum is becoming a high potential and dominant crop in these regions. In north eastern Ethiopia sorghum is typically planted mostly between April and July and harvested from October to December. Farmers cultivate two varieties of sorghums: the long duration or late maturing varieties (produces comparably lower sorghum grain yields) and short duration or early maturing varieties (produce higher sorghum grain yields per ha) (Sorghum value chain context report, 2014). However, farmers prefer the lower yielding longer duration maturing varieties as the biomass is used in the local economy and other diverse uses.

Sorghum became popular to many of small holder farmers particularly who live in areas where water is limited. Its capacity to produce high yields on unfavorable growing condition has made it a well linked crop for many resource poor growers in Ethiopia. But several production constraints hindered its production and productivity. Currently, the crop is produced by 5 million households and its production is estimated to be 4 million metric tons from nearly 2 million hectares of land giving the national average yield of around 2 tons per hectare (CSA, 2012), which is far below the global average of 3.2 tons/ha (FAO, 2010). This low crop production is because of many biotic and abiotic factors.

2.3 Biotic constraints of sorghum crops

Biotic constraints are the primary factors limiting sorghum productivity. Among these several species of insect pests impact the yield of this crop in the country. As compared to maize, three times higher insect pests have been recorded on sorghum in Ethiopia (EIAR, 2014). This might be because Ethiopia is the center of origin of sorghum where it lives with its associated insect pests and natural enemies. However, due to inappropriate management significant yield reduction was recorded due to insect pests on sorghum each year (FAO, 2010).

Among the insect pests *Busseola fusca* (Fuller) *Chilo partellus* and *Sesamia calamists* (Hampson) are the major pests. The exotic, *C. partellus* is the most important problem in Ethiopian sorghum growers. Previous surveys on stem borers have shown that in north eastern Ethiopia, *C. partellus* is the dominant species on sorghum among others **(**Emana Getu *et al*., 2002; Amanueal Tamiru *et al*., 2007; IITA, 2009 & Melaku Wale *et al*., 2016). The pests were reported to have caused damages ranging from significant seedling damage to total sorghum yield losses. Together with *B. fusca,* C. *partellus* causes yield losses of 0 to 100, 39 to 100, 10 to 19 and 2 to 27% from south, north, east and western Ethiopia, respectively (Emana Getu, 2002; Zhou *et al*., 2001 & Asmare Dejen *et al*., 2013).

2.4 Biology of *C. partellus*

Adult *C. partellus* is small sized moth having a wingspan of about 1.9-2.8cm. Fore wings are narrow having a straw or light brown color, while hind wings are papery thin and

white. The forewings of males are pale-brown; those of females are much paler. In males, hindwings are a pale straw color; in females they are white. The moth is nocturnal in habitats and usually lives approximately one week (Mbenga, 2010). *C. partellus* is also commonly called as 'spotted stemborer', 'durra stem borer' and 'maize stalk borer'. However, spotted stemborer is now generally more accepted as the common name of this insect (Maes, 1997). *C. partellus* is a lepidopteran insect belonging to the super family Pyraloidea, family Crambidae and sub family Crambinae. Pyraloidea larvae are distinguished from other lepidopteran larvae by the presence of large circles or ellipses of crochets on the abdominal prolegs (Maes, 1997 & Visagie, 2016).

Mating occurs during the early hours of the day. Females lay eggs on the 2-3 subsequent nights up to 500 eggs in batches of 10-80 overlapping eggs near the midribs on the under surface of the leaves during the evening hours. Eggs are oval with a creamy white colour and approximately 0.8mm in length (Plate 2.1a) (Panchal & Kachole, 2013). Eggs can be found in the field from one week to three weeks after the plant emergence. Hatching takes place early in the morning after plant emergence usually 4-6 days after oviposition.

On hatching larvae feed gregariously for a short time after which they migrate upwards to feed in the whorls of the crop plant. At the 3rd instar stage, larvae migrate from the whorl to bore down into the stem. These larvae tunnel into stem tissue and feed in the inter-nodes for a few weeks and they later develop into pupae after 28-35 days. Final instar larvae (Plate 2.1b) are 25-30mm long and rows of dark spots can be seen on the body (Panchal & Kachole, 2013 & Ateia, 2018). The head capsule and prothoracic shield appears brown. The dorsal surface of the body has four reddish brown or purple

longitudinal stripes (Visagie, 2016). Larvae migration may occur to neighbouring plants if the food is deteriorated, decrease in quality and increase in contact between larvae (Berger, 1995).

Larval development is completed in 24-27 days and has 5-6 instars. The full-grown larva prepares a circular exit hole for the moth just before pupation. Pupation takes place inside the stem after 2-3 weeks of feeding. Pupae are long cylindrical forms that are dark brown in colour and males are smaller in size than the females (Visagie, 2016) (Plate 2.1c). The pupal period takes 7-10 days after which adult moths emerge to complete the cycle.

Adults (Plate 2.1d) emerge from pupae after 5-12 days of pupation; moths live for 3-8 days during which they mate and lay eggs (Panchal & Kachole, 2013). The entire life cycle may be completed within 30 to 40 days (Plate 2.1) in some cases up to three times faster than the life cycle of *B. fusca.* This could cause *C. partellus* to be more competitive than *B. fusca.*

During the off season, the larvae undergo diapauses in plant stalks and stubbles or in stem bases beneath the soil. The hibernation sites provide insulation and shelter (Kfir *et al*., 2002). However, a rise in temperature and the arrival of the first spring rains are the two most important factors for breaking diapause of overwintering larvae. Thus, with the onset of rain, larvae pupate and adult emerges in 7 days. During the entire crop season, three to four overlapping generations may occurs in the field (Mbenga, 2010).

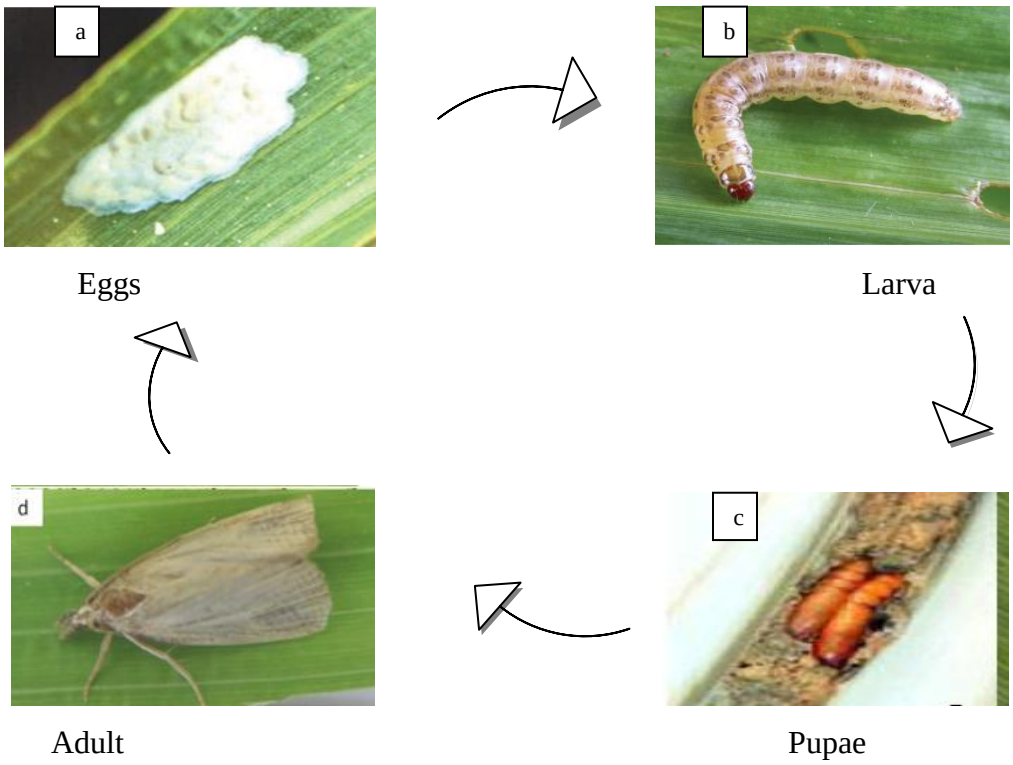

Plate 2.1 Life cycle of C. partellus: a) eggs b) larva c) pupa and d) adult

2.5 Distribution

Various reports indicate that *C. partellus* is distributed throughout the world wherever sorghum is grown in the lower warmer areas (Zhou *et al*., 2001; Emana Getu *et al*., 2001; Overholt *et al*., 2001; Kfir *et al*., 2002 & Chinwada *et al*., 2003). This pest is the most important problem to maize and sorghum growers in various sorghum growing countries of the world (Muturi *et al*., 2012 & Sylvain *et al*., 2015). In Africa alone, the pest is reported to have infested sorghum from different countries including Kenya, Ethiopia, Somalia, Lesotho, Mozambique, South Africa, Swaziland, Zambia, Botswana, and Zimbabwe (Overholt *et al*., 2001; Emana Getu *et al*., 2002 & Kfir *et al*., 2002). Moreover, the predicted eventual distribution included several countries in south western

and western Africa where the pest is not yet known to occur (Overholt *et al*., 2000 & Emana Getu *et al*., 2001).

In Africa the pest has also been known to coexist with the native stem borer species in many areas in the moist mid-altitude and moist transitional agro ecological zones (Polaszek, 1998; Ofomata *et al*., 2000 & Amanuel Tamiru *et al.,* 2007). However, it has been reported to competitively displace the native stem borer species such as *B. fusca*, *S. calamistis*, *Chilo orichalcociliellus* and *Eldana saccharina* in the region and it became the domoinant stem borer (Kfir, 1997; Kfir *et al*., 2002 & Sylvain *et al*., 2015).

One of the possible reasons for the displacement of indigenous species by *C. partellus* is that hibernating larval populations of *C. partellus* terminate diapause and emerge as a moth earlier than *B. fusca* and other native species (GuoFa *et al*., 2001). In addition, its life cycle is three weeks shorter than that of the native stem borer species, *B. fusca* which gives it a further competitive advantage because of its higher potential rate of increase. In Ethiopia, Assefa Gebre-Amlak (1985) recorded *C. partellus* at an elevation range of 510 to 1700m and in warmer areas of the country. However, Emana Getu *et al*. (2001 & 2002) reported for the first time the niche expansion of *C. partellus* to the higher elevation. Recent report indicated that *C. partellus* occurred at elevations as high as 2088 meters above sea level (Amanuel Tamiru *et al.*, 2012). This shows the potential distribution of this pest in the high land areas of the country.

2.6 Host range

C. partellus is among the phytophagous insects that occurred on several wild and cultivated host plants. But, this pest has occurred in wild hosts before the domestication of sorghum (Rebe, 2002). *C. partellus* is associated with a wide range of wild hosts belonging to the families Poaceae, Cyperaceae and Typhaceae for millions of years (Le Ru *et al*., 2006 & Visagie, 2016**).** Previous studies revealed that *C. partellus* can survive in wild grasses more than other indigenous stemborer species (Ofomata *et al*., 2000; Songa *et al*., 2002 & Maddonni *et al*., 2006). For example, a survey that was conducted in Kenya, Tanzania and Uganda indicated that *B. fusca* was not common in wild hosts, showing its relative preference for cultivated hosts (Le Ru *et al*., 2006). However, a related study revealed that *C. partellus* to be the most common borer species in wild host plants (Kfir *et al*., 2002 & Khadioli *et al*., 2014). In line with this study, the success of *C. partellus* is probably centered on shifting from wild to cultivated hosts and vice versa.

2.7 Pest status of *C. partellus*

The year of first report of infestation on its host markedly varied among African countries. *C. partellus* was first reported from Malawi in 1930 (Emana Getu *et al.,* 2001 & Overholt *et al*., 2001), but it was reported to have been recorded infesting maize and sorghum in Ethiopia in 1970' (Emana Getu, 2001 & Melaku Wale *et al*., 2006). Since then, the pest is reported as a dominant pest mainly from the warmer low land areas of northern and eastern parts of the country.

Its pest status has increased in cultivated crops since maize and sorghum crops create continuous availability of resources (Overholt *et al*., 1997 & Mwalusepo *et al*., 2015). Besides, in areas where host plants are abundantly found and climate is conducive for its development, *C. partellus* is known to be active all year round (Khadioli *et al*., 2014). This may be due in part to its high potential with respect to colonizing new environments and ability to utilize a diverse range of hosts (Kfir, 1997 & Overholt *et al*., 1997). It is therefore likely that *C. partellus* adjusts faster to the wild grass hosts and that it colonizes the suitable feeding niches in these habitats much earlier than the other stem borers. Therefore, with its short life cycle, as well as host plant switching potential coupled with quick diapause termination, it can rapidly increase its population, thus ensuring a numerical advantage over other native stemborer species.

Depending on the level of infestation, losses due to this insect pest could reach up to 100% in Ethiopia (Emana Getu & Tsedeke Abate, 1999 & Asmare Dejen, 2008). Crop losses are caused through the feeding of larvae; resulting in destruction of growing point, stem breakage, disruption of nutrient translocation, stunting, stem lodging and direct damage to ears (Polazsek, 1998 & Kfir *et al.*, 2002). Even though the pest is most known for its severe damage to grain sorghum, it has the potential to attack other important crops such as pearl millet, finger millet, rice, wheat, sugar cane, foxtail and various grass species including Sudan grass and Napier grass (Kfir *et al*., 2002 & Matama-Kauma *et al*., 2008).

2.7.1 Infestation on sorghum

C. partellus infestation varied from district to district, crop growth stages, type and variety which could be due to varied area under sorghum cultivation as well as differences in the climatic conditions. Sorghum plants are infested two weeks after germination. However, infestations occur in all developmental stages of sorghum starting from seedling to maturity causing crop losses of between 50% and 100% in small-scale farmers' fields (Assefa Gebre-Amlak, 1985; Emana Getu & Tsedeke Abate, 1999 & Kfir *et al*., 2002). Frequently, up to 100% of plants are infested in some parts of Africa where *C. partellus* is the most abundant species (Kfir *et al*., 2002 & Cugala *et al*., 2006). When infestation is severe there is a physiological disruption of plant growth, panicle emergence and grain formation resulting in reduction in kernel number and mass (Addo-Bediako & Thanguane, 2012 & Panchal & Kachole, 2013).

Cultural practices such as keeping the stubbles in the field, crop residues stacked for animal feed and construction purposes and elimination of parasitoids by applying pesticides are the major causes of infestation. In South Africa, Kfir *et al*. (2002) reported high infestations by stem borers on sorghum due to partial elimination of parasitoids by applying pesticides. The first symptoms of *C. partellus* attack on young plants noticed from 2-3 weeks after seedling emergence. Foliar damage and dead heart occurs when whorl leaves are attacked, by first and second instar larvae resulting in reduction in total leaf area and photosynthetic capacity of the plant. In older plants larvae tunnel the stem, feed on the internal tissues and the grain inside the enclosed panicle (Kfir, 1994 & Habib, 2005).

In earlier studies stem tunneling was recorded by several authors: For example, Reddy *et al*. (2003) recorded stem tunnels of 1-6cm in length in the pith filled with excreta by *Sesamia inferens* (Walker) in maize. Tadele Tefera and Pringle (2004) also recorded a stem tunnelling of 1-5%. Mallapur *et al*. (2012) recorded maize stalk infestation by stem borers at the time of harvest in the farmer's fields. Tunneling in older sorghum plants may cause the plant weakens leading to breakage of stems and more importantly interferes with supply of nutrients to the developing grains by destroying the plant's vascular system and resulting in chaffy heads (Kfir *et al*., 2002 & Tadele Tefera, 2004).

2.7.2 Economic impact

Infestation on sorghum plants usually results in crop losses as a consequence of death of the growing point (dead heart), stem lodging and direct damage to the ears resulting in significant yield loss. In Africa the damage caused by *C. partellus* on sorghum crops may lead to more than 50% yield reductions (FAO, 2010 & Mailafiya *et al*., 2011). In different parts of Africa sorghum yield losses have been reported. The pest causes more than 15%-45% yield loss in sorghum in east Africa (Muturi *et al*., 2012) and greater than 50% in South Africa (Kfir *et al*., 2002 & GRDC, 2009). It is reported that damage by *C. partellus* is not only limited to maize and sorghum crops but also to several wild grass families (Ofomata *et al*., 2000; Songa *et al*., 2002 & Le Ru *et al*., 2006).

2.8 Management options

Like other pests, *C. partellus* causes deleterious threats to the host plants which interfere with sorghum growers' interest. Therefore, it has to be controlled to minimize its

economic impact on sorghum crops. *C. partellus* has been controlled by cultural, botanical, host plant resistance, chemical and biological control methods (Emana Getu & Tsedeke Abate 1999; Ferdu Azerefegne *et al*., 2001; Mills & Daane, 2005; Asmare Dejen *et al*., 2010 & Khan *et al*., 2015).

2.8.1 Cultural control

Cultural control is a labour-intensive traditional method. However, this method is a better alternative to pesticide application from conservation of non-target insects, environmental and other health concerns points of view. In relevance to control of *C. partellus*, this method includes practices such as appropriate crop residue disposal, planting date manipulation, destruction of volunteer and alternative host plants, tillage practices, crop rotation and intercropping (Emana Getu *et al*., 2001 & Tekle Abuhay, 2016).

Sorghum stalks and stubbles left standing in the fields are an important source of initial population of *C. partellus* and they form the primary source of infestation in the following season. Thus, appropriate disposal and/or management of crop residues (stalks and stubbles) after harvest can reduce carry-over populations of diapausing larvae and so limit the initial establishment of the following season's crop (Emana Getu *et al*., 2001).

Manipulation of planting date can be an effective measure to escape serious borer attack. However, in order to efficiently utilize planting date it is important to know the local seasonal pattern of borer life cycle. Later sowing of sorghum is more affected by larvae than earlier sowings as it disrupts its seasonal cycle. It is thought that at the start of the

rainy season, borer populations arising from diapausing-generation larvae will still be building up, so fewer moths will oviposit on early planted crops (Emana Getu *et al*., 2001 & ISU, 2012). In Ethiopia, the infestation of late-sown maize, attacked by the second generation of *B. fusca* was higher (22-100) than early-sown maize (0-22%) attacked by the first generation (Emana Getu & Tsedeke Abate, 1999 & Ebenebe *et al*., 2013).

Destruction of volunteer and alternative host plants reduce overwintering and hibernation of the borer. Stubble is possibly the main source of initial *C. partellus* infestation in subsequent seasons. Leaving the sorghum plants in the field for a long time after physiological maturity will increase yield losses from pests' activities. Hence removal and burning of the stalks will ensure protection of crops (Wahedi *et al*., 2016). However, it is unacceptable for the farmers since sorghum or maize stalks are utilized for different purposes (Haile Adugna & Hofsvang, 2001; Kfir *et al*., 2002 & Solomon Tesfay, 2014). Deep ploughing is effective as it brings the larvae and pupae to the soil surface. The larvae will be then exposed to heat from the sun and predators which significantly minimize the density of insect pests.

Tillage reduce borer populations either by burying them deeply into the soil or by exposing the larvae to adverse weather conditions and biotic factors such as birds, rodents, ants and other natural enemies (Mashwani *et al*., 2015). Slashing maize and sorghum stubble destroyed 70% of *C. partellus* populations. In South Africa study report showed that ploughing and disking destroy 24% of the pest population in sorghum and 19% in maize (Tekle Abuhay, 2016).

Intercropping of sorghum with non-host plant is known to control stem borer pests (Mills and Daane, 2005). Intercropping of sorghum with non-host plants significantly decreased levels of infestation by stem borers in the main crop and also increased larval parasitism. Volatile compounds produced by *Melinis minutiflora* repelled female stem borer, *C. partellus* and attracted foraging female parasitoids (Emana Getu, 2001 & Solomon Tesfay, 2014). One of the volatile compounds produced when in contact with *M. minutiflora* attracts parasitoids. This volatile compound is also released by herbivore damaged plants and is implicated more widely as cue for stimulating predation and parasitism (Khan *et al*., 1997). In Ethiopia, Emana Getu (2001) reported that stem borer infestation decreased and parasitism increased when maize intercropped with beans. It was also possible to reduce maize yield losses due to stem borer by intercropping with cassava, cowpea and soybean in Cameroon (Chabi-Olaye *et al*., 2005).

2.8.2 Control by use of Botanicals

Botanicals are insecticides derived from plants containing potent bioactive compounds which are responsible for insecticide properties. These compounds act as contact poisons, ingestion or stomach poisons; as repellents, driving the insects away due to smell or taste; as antifeedants, reduces the food intake of the insect and starve them to death; as deterrence, prevents the moth larvae from feeding and they starve; as oviposition deterrents, preventing insects from egg laying; or as inhibitors, leading to death by interfering with the life cycle of the insects (Mills & Daane, 2005; Thippeswamy *et al*., 2010; Sarwar, 2012; 2015; Islam *et al*., 2013 & Kareru *et al*., 2013).

Several plant extracts have been studied and found to be effective against stem borers' insects in Ethiopia and other parts of the World. Field experiment conducted in southern Ethiopia on extracts of fruits of chinaberry (*Melia azedarach* L.), endod (*Phytolacca dodecandra* L.) and pepper tree (*Schinus molle* L.) has showed significant reduction on the levels of leaf infestation and dead heart injury due to larvae of the maize stalk borer, *B. fusca* and resulted in increases in maize yield (Assefa Gebre-Amlak & Ferdu Azerefegne, 1999).

Another field experiment conducted by Amaugo and Emosairue (2003), in Nigeria on the efficacy of aqueous and acetone extracts of neem seed kernel (*Aadrichata indica* A. Juss), nutmeg (*Monodora myristica* Gaertn.), Dunal and physic nut (*Jatropha curcas* L.), and castor oil (*Ricinus communis* L.) on upland rice stem borers, reduced the percent dead heart and white heads caused by stem borers and resulted in high yield.

In addition, plant extracts of *A. indica*, *Caloptropis* sp. (Ak), Colocynth, *Citrullus colocynthis* and tobacco, *Nicotiana tabacum* L. extracts were evaluated against yellow rice stem borer, *Scirpophaga incertulas* Walk. and have resulted in the lowest number of dead hearts, white heads, number of productive tillers and filled grains than the un-treated check. In addition neem was found to attract many predators (Dhuyo & Soomro, 2007). Similarly, study report from Bangladesh indicated that neem extracts, *A. indica* at 15ml/L concentration reduced dead heart and white head by 38.3% and 58.1%, respectively (Islam *et al*., 2013). Neem products (powder from ground neem seeds) are also reported being effective and may be applied on the leaf whorl in a 1:1 mixture with dry clay or sawdust.

2.8.3 Biological control

Biological control is the use of natural enemies to reduce the damage caused by noxious organisms to tolerable level. The most known natural enemies used as bio-control agents in frequency of their use include parasitoids (parasitic wasps and flies) predators (some insects, spiders and predatory mites) and pathogens (fungi, protozoa, bacteria and virus) (Mills & Daane, 2005).

Predators such as ants, spiders, ladybird beetles and earwigs can cause high mortality of eggs, and young larvae of *C. partellus* in some areas of Africa including Ethiopia (Emana Getu, 2002). In Kenya, Bonhof (2000) reported *Diaperasticus erythrocephala* Oliver and the black ants, *Camponotus rufaglaucus* (Jerdon) on eggs and larvae of *C. partellus*, while ladybird beetls, *Chelomenes sulphurea* Oliver (Coleoptera: Coceinellidae) are eggs and early larval instars predators of *C. partellus*. *Forficula auricularia* L. (Dermaptera: Forficulidae) is an important predator of eggs and larvae of *C. partellus* in Ethiopia (Emana Getu *et al*., 2001) (Table 2.1). Predators being polyphagus and mobile are difficult to manipulate in a habitat. However, some predators such as ants, coccinellid beetles, anthocorid bugs and earwigs have been effective bio-agents against stem borers in different agro-ecosystems. Thus, if they are provided with suitable conditions and habitat for their survivals, through conservation and augmentation they can be used as bio-agents in pest management as their utilization is economical, eco-friendly and compatible with other pest control methods.

Pathogens such as fungus, bacteria, protozoa, virus and nematodes are considered important bio-control agents in suppressing *C. partellus* populations. However, the

impacts of naturally occurring pathogens are often mitigated by long dry periods between cropping seasons and lack of physical contact between larvae of the stem borer, *C. partellus*. In Africa, pathogens that were recorded to infest *C. partellus* mainly include *Aspergillus* spp., *Beauverria bassiana*, *Metarhizium* sp., Baculoviridae (Granulosis virus), Microsporidae, Gregarinae, Nosema sp. and Bt among others (Table 2.2).

Nematodes that were recorded from *C. partellus* include *Panagro lamimus*, *Hexamemis* sp., *Steinernema intermedia, Hetrerhabditis* sp. (Emana Getu, 2002). Of the various bio-control agents considered, the entomopathogenic fungi, *M. anisopliae* and *B. bassiana* (Tadele Mekonnen & Tadele Tefera, 2011) have received great attentions as a viable alternative to chemical pesticides. In Ethiopia, these strains have been identified from different parts of the country, studied and proved to be effective against a broad range of insect pests.

Studies revealed that many strains of both isolates show high level of mycosis in laboratory based experiments. Small scale applications of these pathogens have been found to be effective against *C. partellus* (Tadele Mekonnen & Tadele Tefera, 2011). In Ethiopia Tadele Tefera and Pringle (2004) stated that *B. bassiana* and *M. anisopliae* (Metsch.) treated plots reduced stem tunneling, dead heart, number of attacked nodes and holes of 1-5, 0-33, 0.3-2.5 and 0.2-3.3 percent, respectively in maize. Nematodes and microbial pathogens have been reported to infect all stages, but their impact is low under natural condition (Kfir, 1994). Likewise, pathogens and predators have been reported to cause high mortality in some regions, but their abundance is highly dependent on location and season.

Parasitoids are the most important bio-control agents in suppressing *C. partellus* populations. Several parasitoids in east Africa attack eggs, larvae and pupae of *C. partellus*. Parasitoids of different families have been recorded in Africa from *C. partellus*. All recorded parasitoids were insects mainly parasitic Hymenoptera, but also Tachinidae. The three families of predominant larval parasitoids recorded include: Braconidae, Ichneumonidae and Tachinidae. Braconids accounts for 35% of parasitoids recorded on *C. partellus* (Emana Getu *et al*., 2001; 2002; Zhou *et al*., 2001 & Songa *et al*., 2002). Although predators and pathogens cause mortality, parasitoids have been the primary target as bio-control agents. This is probably due to their ecological diversity, host specificity and ability to attack hosts that feeds cryptically within the host plant stem (Obonyo *et al*., 2008).

Several egg, larva and pupa parasitoids were recorded by different authors in Ethiopia. These include, *Dolichagenidae fuscivora* (Walker), *Bracon sesamiae* (Cameron), *Cotesia sesaimae* (Cameron) and *Bracon hebator* (Say) were dominant larval parasitoids of *C. partellus* among others. *Procerochasmias nigromaculatus* (Cameron) and *Denlichasmiasis busseolae* (Heinrich) were also important pupal parasitoids of *C. partellus* in Ethiopia (Emana Getu *et al*., 2001 & Emana Getu, 2002). Telenomus and Trichogramma species are the most abundant and widespread egg parasitoids in east African countries (Ahmed *et al*., 2003). The main parasitoids of *C. partellus* in Africa are listed in (Table 2.3) which include both indigenous and exoitic species including the introduced species to Africa for classical biological control of *C. partellus*.

Table 2.1 Commonly recorded predators of *C. partellus* in Africa

Order/Family	Predators	Host stage attacked	Reported from
COLEOPTERA			
Coccinellidae	*Cheilomenes sulphurea* (Oliver)	Eggs	Kenya
	Cheilomenes propinqus (Mulsant)	Eggs	Kenya
DERMAPTERA			
Forficulidae	*Diaperasticus erythroceophala* (Oliver)	E/L	Kenya
	Forficula auricularia (Linnaeus)	E/L	Kenya, Ethiopia
HETEROPTERA			
Anthocoridae	*Orius* sps.	Eggs	Kenya
HYMENOPTERA			
Formicidae	*Pheidole megacephala* (Fabricius)	E/L	Uganda

E/L – Egg or larva

Table 2.2 Commonly recorded pathogens of *C. partellus* in Africa

Family	Pathogens	Host stage attacked	Reported from
Fungi	*Aspergillus* sps.	Larva	Kenya
	Beauveria bassina (Vuillemin)	Eggs	Kenya
	Metharhizium anisopliae (Var. anisopline)	E/L	Ethiopia
	Paecilomyces fumosoroseus (Wize)	Eggs	??
Bacteria	*Bacillus thuringiensis* (Berliner)	L	Kenya, Ethiopia
Viruses	*Baculoviridae* (granulosis virus)	L	Kenya
	Polyhedral inclusion bodies	L	Kenya
Nematodes	*Hexamermis* sp.	L	Kenya,Uganda, Tanzania, Ethiopia

E/L – Egg or larva

Table 2.3 Commonly recorded parasitoids of *C. partellus* in Africa

Family	Parasitoids	HSA	Reported from
HYMENOPTERA	*Cotesia flavipes* (Cameron)	Larva	Ethiopia, Kenya, Uganda, Tanzania
Braconidae	*Cotesia sesamiae* (Cameron)	Larva	Africa
	Bracon sesamiae (Cameron)	Larva	Senegal, Cameron, Tanzania, Uganda, S.Africa, Ethiopia
	Bracon hebetor (Say)	Larva	Cosmopolitan
	Dolichogenidea polaszeki (Walker)	Larva	Kenya, Ghana, Nigeria, Malawi, Benin, Uganda, Zambia, Ethiopia
	Dolichogenidea fuscivora (Walker)	Larva	Ethiopia
	Stenobracon rufus (Szepligeti)	Larva	East Africa
	Chelonus curvimaculatus (Cameron)	Larva	Kenya, Sudan, Somalia, Ethiopia, Senegal, S. Africa, Tanzania, Uganda, Zambia, Kongo, Zimbabwe
Ichnonmoidae	*Denthchasmias busseolae* (Heinrich)	Pupa	Cameron, Kenya, Malawi, Nigeria, Mozambigue, Burkinafaso, Uganda
	Procarochasmias nigromaculatus (Cameron)	Pupa	Seralion, S. Africa, Ethiopia, Kenya, Tanzania, S. Africa, Uganda, Mozambiqe, Zimbabwae, Cameron
	Xanthopimpla stemmator (Thunberg)	Pupa	S & E Africa, including Ethiopia
	Xanthopimpla citrina (Holmgren)	Pupa	Kenya, Nigeria, Tanzania, Ethiopia
Chalcidodae	*Psilochalcis soundanensis* (Steffan)	L-P	Kenya, Cameron, Ghana, Mali, Niger, Nigeria, Senegal, Sudan, Uganda, Mozambique, Ethiopia
Eulophidae	*Pediobius furvus* (Gahan)	L-P	Eastern, Western & Southern Africa
Eurytomidae	*Eurytoma oryzivora* (Delvare)	L	Western and Eastern Africa
Trichogrammatidae	*Trichogramma* spps.	Eggs	Uganda, Ethiopia
	Telenomus spps.	Eggs	Ethiopia
DIPTERA			
Tachinidae	*Sturmiopsis parasitica* (Curran)	L	Eastern, West and Southern Africa

L- larva, L-P – larva or pupa

Source: Emana Getu (2002)

2.8.3.1 *Cotesia flavipes* (Cameron)

C. flavipes is commonly called parasitic wasp belongs to the Order Hymenoptera, super family Ichneumonoidea, family Braconidae and Genus *Cotesia* (Mason, 1981; Kimani-Njogu & Overholt 1997 & Muirhead *et al*., 2008). However, there were times when it was known by its Synonym: *Apanteles flavipes*. The adult wasp is small about 3-4mm in length and lives for only a few days (about 1-3 days) but when provided with food (honey) they can live up 6 days (Potting *et al*., 1997 & Zhou *et al*., 2001).

C. flavipes is a gregarious larval endo-parasitoid of species complex that is used in biological control of several lepidopteran stem borers (Muirhead *et al*., 2006 & Murthy *et al*., 2011). *C. flavipes* shows sexual dimorphism. Sexes can be distinguished by observing their antennae. Adult female antenna is robust and shorter than the body (Plate 2.2b), while the antennae in male are longer than the body; nearly all segments are longer than breadth (Plate 2.2a).

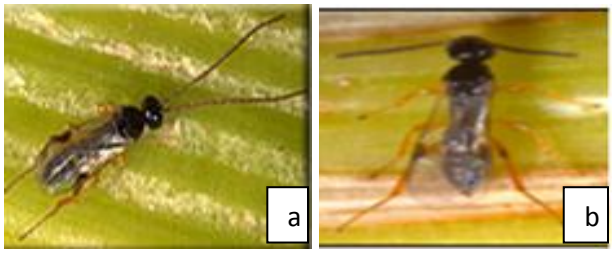

Plate 2.2 Adult *C. flavipes* male and females: a) male b) female

Source: (Muirhead *et al*., 2006)

2.8.3.1.1 Biology and Ecology of *C. flavipes*

Life cycle of *C. flavipes* begins when females lay a maximum of 30-40 eggs into at least two different host larvae (Sallam *et al*., 2001). As compared with other complexes this low egg allocation by females may be due to depletion of eggs after they have parasitized 4-5 hosts (Potting, 1997 & Sallam, 2006). Eggs hatch after about 3 days; larvae develop through 3 instars within the host larva feeding on body fluids (plate 2.3b). The egg-larval period takes about 12-15 days at 25^{o} C, 50-80% relative humidity (RH), and a photoperiod of 12:12 (L:D) hr. The final larval instars emerge from the host body by chewing through the larval integument and immediately spin a cocoon and pupate. The silicon cocoons of small Braconids larva can often be seen on the outside of the body of hosts, caterpillars (Plate 2.3c).

Adults emerge after 5-7 days later with the same RH (plate 2.3a). High light intensity increases activity and ensures mating. Usually, adults emerge in the morning hours of the day and mating begins soon after emergence (Ahmed *et al*., 2003 & Obonyo *et al*., 2008). The total life cycle is about 20 days (Plate 2.3). The foraging strategy of *C. flavipes* involves entering the holes in the host plant stem and searching for the larvae host in the tunnels (Moonga, 2007). In host finding, plant volatiles and host frass are important cues (Varkonyi *et al*., 2002 & Moonga, 2007).

Life cycle of *Cotesia flavipes*

Complete metamorphosis

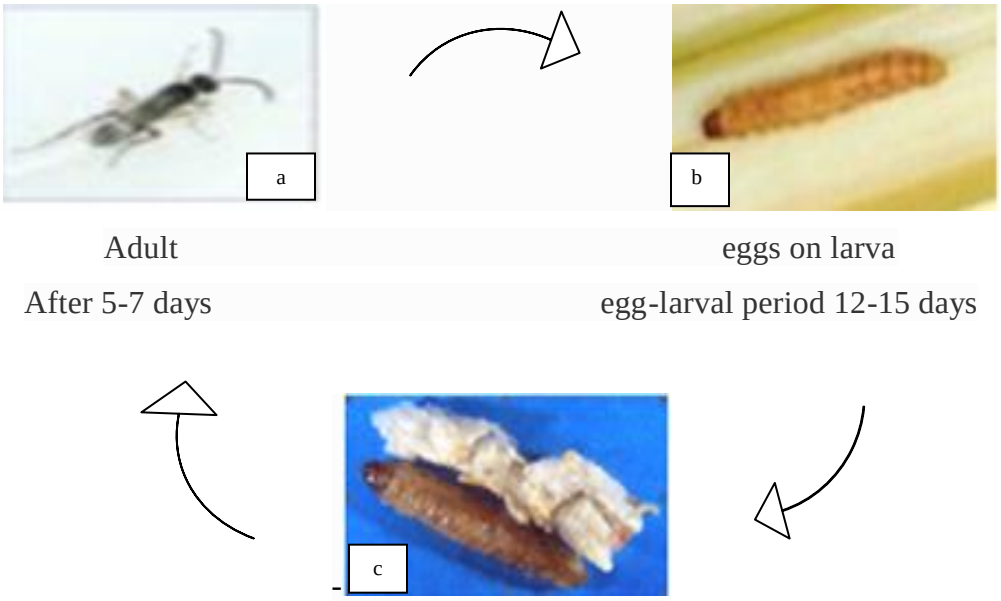

Plate 2.3 Life cycles of *C. flavipes*: a) adult b) larva c) cocoons

There are three morphologically similar species of Cotesia which attack stem borers: *Cotesia flavipes*, *Cotesia sesamiae* and *Cotesia chilonis* (Matsumura) (Potting 1997 & Muirhead *et al*., 2005). The species of *C. flavipes* complex are thought to be endemic to the following areas: *C. flavipes* to the Indo-Australian region, *C. sesamiae* to central and southern Africa and *C. chilon* is to eastern Asia, including Japan (Muirhead *et al*., 2006). However, all three species have been utilized for classical biological control of stem boring insect pests. These species were originally difficult to separate using morphological characters. However, the external morphological characters of the species

showed a high degree of intra-specific variation particularly in colour, density of setae and surface sculpture which could be used for identification. Thus, these characters such as number of hairs on the scutellum, the scuto-scuteller sulcus and the rugosity on the propodeum could be used to separate the females and males in the complex (Muirhead *et al*., 2005).

C. flavipes is morphologically similar with that of the endemic *C. sesamiae*. However, these two species are distinguished by examination of male genitalia. The male genitalia of *C. flavipes* are slender and elongated while those of *C. sesamiae* are robust, short and are about half the length of *C. flavipes* male genitalia (Sallam *et al*., 2001 & Muirhead *et al*., 2008). Thus, males of the two species are easily distinguished from females because they have longer antennae **(**Songa *et al*., 2001 & Muirhead *et al*., 2008**).** However, it is very difficult to distinguish between the species when there are no males produced in the progeny. The punctuation (certain marks) and pubescence on the mesosoma and metasoma as well as the shape of the scutellum are also used for identification. *C. flavipes* has a sparsely punctuate mesonotum and its scutellum and propodeum are narrow, while *C. sesamiae* has an enlarged propodeum and a uniformly punctuate mesonotum.

Mohyuddin (1971) as cited in Muirhead *et al*. (2005) stated that cocoons could also be used to differentiate between the two species because those of *C. flavipes* are closely packed (Plate 2.4a) while those of *C. sesamiae* are loosely packed (Plate 2.4b). Apart from morphological structures, the parasitoids can also be distinguished from each other by using allozyme frequencies and mating experiments with laboratory populations of *C.*

flavipes (Kfir *et al*., 2002). Currently much recent progress has been made in species identification using mating behavior and molecular data (Sallam *et al*., 2001 & Muirhead *et al*., 2012).

Plate 2.4 Cocoons of (a) *C. flavipes* and (b) *C. sesamiae*

The two species exhibit very similar ecological niches, especially in lowland areas. Even if, *C. flavipes* and *C. sesamiae* can occupy a similar ecological niche it has been shown that they prefer different host species and are not likely to compete (Sallam *et al*., 2001 & Songa *et al*., 2001). Several indigenous as well as exotic stem borers are hosts of *C. flavipes.* According to the study of Kfir *et al*. (2002) *C. flavipes* is commonly recovered from larvae of several exotic and indigenous stem borer species on different cereal crops in many areas of sub-Saharan African countries. Though *C. flavipes* is capable of parasitizing a fairly wide host range of noctuid and pyralid stem borer species, it does not produce progeny on the local stem borer, *B. fusca* which is a suitable host for the development of *C. sesamiae* (Brodeur, 2012). However, *C. flavipes* is extrinsically superior to *C. sesamiae* when *C. partellus* is the host and equally competitive when *S. calamistis* is the host (Potting *et al*., 1997).

Current studies are investigating the competitiveness of the two parasitoids within the same host (multiple parasitisms) (Ngi-Song *et al*., 2001 & Muturi *et al*., 2014). The study

indicated that there will be the displacement of species during competition. It is generally agreed that the displacement of a natural enemy by a second can only occur if the second one is more effective and therefore should result in better host population regulation (Potting *et al*., 1997 & Brodeur, 2012). Therfore, if the host is suitable for *C. flavipes* then competitive displacement may eventually occur particularly in areas where *C. partellus* is dominant. According to the reports of several studies *C. flavipes* is better adapted to drier climates than *C. sesamiae* on *C. partellus*. Thus, *C. flavipes* is a more efficient larval parasitoid and therefore increased suppression of *C. partellus* populations in low warmer areas.

2.8.3.1.2 Introduction, release and establishment

Classical biological control involves the introduction of exotic natural enemies against introduced pest species. The larval parasitoid, *C. flavipes* has been introduced into more than 40 countries of the world to control native and exotic stem borers (Matama-kuuma *et al*., 2001; Cugala, 2002 & Cugala *et al*., 2006). In east Africa it was imported into Kenya from Pakistan in 1991 by the international centre of insect physiology and ecology (ICIPE) to investigate its potential for suppressing *C. partellus* population (Overholt *et al*., 1994 & Emana Getu *et al*., 2001). For a second time it was released in1992 and is now considered to be established in Kenya and Tanzania (Overholt *et al*., 1997; Kfir *et al*., 2002; Emana Getu, 2002 & Omwega *et al*., 2006).

C. flavipes could be released both as adults and as cocoons. However release of cocoons is a preferred method as it maximized the effective lifespan of the adults in the field. In addition, releasing cocoons is a simple method at the time of visit to the field. The

cocoons could be placed in the field at anytime during 5-6 days window of opportunity. However, cocoons placed in a 'release station', should be protected from pathogens, predators and rainfall (Chinwada *et al*., 2003 & Harrison *et al*., 2012). Adults live only a few days (Overholt *et al*., 2001) whereas the cocoon stage lasts 5-6 days (Kfir, 1994). Thus, if adults which emerged in the laboratory were released a significant portion of their adult life span could have passed before liberation, particularly if release sites were distant from the rearing laboratory.

Following its introduction into east Africa it was also released to other 11 African countries and has become established in 10 of these (Overholt *et al*., 1994; Zhou *et al*., 2001; Songa *et al*., 2001; Cugala, 2002 & Chinwada *et al*., 2003). Accordingly, it became established at the majority of release sites and spreading to new areas where it has not been released. In Ethiopia this parasitoid has never been released but Emana Getu (2002) found established for the first time on *C. partellus, B. fusca*, and *S. calamistis* in all major maize and sorghum growing areas of the country. His study suggested that its spread into Ethiopia may be from populations released in Kenya and Somalia to become the major parasitoid of *C. partellus* in maize and sorghum fields.

Similarly, Assefa Yihunie *et al*. (2008) reported its recovery from *C. partellus* in sugarcane, *Saccharum* spp. hybrids at a site >2,000km from the nearest known release sites in Kenya and Somalia. Thus, this recovery in a sugarcane field at Wongi estate may indicate its permanent establishment in the country and its potential as a bio-control agent in stem borer management. *C. flavipes* is now established in several countries of Africa including Kenya, Tanzania, Uganda, Mozambique, Zambia, Zimbabwe, Ethiopia,

Zanzibar, Malawi and Somalia (Emana Getu *et al*., 2001; Cugala *et al*., 2006 & Assefa Yihunie *et al*., 2008). As a result of this, today *C. flavipes* is promising to give satisfactory levels of *C. partellus* control in Mozambique (Cugala, 2002) Kenya (Songa *et al*., 2001), Ethiopia (Emana Getu, 2002), Tanzania (Nsami *et al*., 2001), Uganda (Matama-Kauma *et al*., 2001) and Zambia (Mushore, 2005).

On the other hand, in South Africa 13 species of parasitoids were introduced over 16 years to control a complex of borer species but none has established (Kfir, 1994). Likewise, in Zimbabwe *C. flavipes* have been first released in July 1999. Releases were also conducted in 2000 and 2001. However, up to 2001 establishment had not occurred (Chinwada *et al*., 2003). Studies indicate that establishment of the species has varied from country to country and within country suggesting that biotic and abiotic factors such as parasitoid host, temperature and relative humidity may influence parasitoid performance (Kfir *et al*., 2002 & Emana Getu *et al*., 2004). Hence, studying the geographical distribution and host range of a natural enemy is required prior to its introduction.

In general, for the parasitoid to establish there must be physiological compatibility between the parasitoid and its host. This is because host unsuitability is one of the factors for the lack of establishment (Overholt, 1998 as cited in Mushore, 2005). The other important factors for *C. flavipes* to successfully establish in a new environment include: climate compatibility, habitat stability and old host/parasitoid associations among others (Kfir, 1994; Ngi-Song *et al*., 2001; Gohole & Ngi-Song, 2001 & Brodeur, 2012). The probability of establishment and the level of suppression of the stem borer complex may

depend not only on the old host/parasitoid relationship(s) but also on the compatibility of the new relationships (Chinwada *et al*., 2003). Compared with new associations, old host-parasitoid associations are more likely result in establishment (Overholt *et al*., 1994). However, as stem borers typically occur in complexes and thus introduced parasitoids will often encounter both old and new host association when colonizing a new area.

2.8.3.2 *Xanthopimpla stemmator* (Thunberg)

X. stemmator is a solitary endoparasitoid of lepidopteran stemborers. The parasitoid attacks pupae of *C. partellus* and several other stemborers in Asia (Chinwada *et al*., 2004 & Gitau *et al*., 2005). Following the introduction of *C. flavipes* into east Africa efforts are being made to introduce a second parasitoid, *X. stemmator* to further improve biological control of *C. partellus* and other stemborers. In east Africa, pupal parasitism is low and usually less than 3% however it can attain levels of 16% (Zhou *et al*., 2003). So the solitary pupal parasitoid, *X. stemmator* was imported to eastern Africa in 2000 by ICIPE to complement the action of other parasitoids (Gitau *et al*., 2005 & Muturi *et al*., 2006). The parasitoid has been recently imported and released in several countries of Africa to control the exotic *C. partellus* including Ethiopia (Emana, personal communication). The release of this parasitoid in Ethiopia was made around Kombolcha of South Wollo zone, north eastern Ethiopia; however its establishment in the area has not been assessed yet.

2.8.4 Chemical control

Synthetic insecticides of various types are used to control stemborer insect pests in sorghum fields. The use of insecticides may give faster solution for the time being. But,

it is obvious that the use of insecticides in *C. partellus* control bears adverse effects on the ecosystem; non target species including natural enemies of the pest. The cryptic feeding behaviour of the larvae is another problem and thus regular sprays may be required for effective control of this pest as well. However; subsistence farmers in developing countries like Ethiopia cannot afford.

In most cases, controlling *C. partellus* is difficult because most part of its life is spent inside the plant which serves as a physical protection to insecticide application Sallam & Allsopp, (2002). So, chemicals should be used early in the cropping season before larvae penetrated deeply into the sorghum stem (Kfir *et al*., 2002; Khan *et al*., 2015; Valencia *et al*., 2006; Gupta *et al*., 2010 & Solomon Tesfay, 2014). However, it is possible to use insecticides with great success by knowing the ecology and biology of the pest. Identifying the most susceptible stage in its life cycle is however necessary to ensure timely and effective chemical control.

Chemical control can be achieved by the applications of granules or dusts into the leaf whorl early in crop growth stage to kill early larval instars. But, this method has limited effectiveness once the larvae bore into the stem. Therefore, systematic insecticides are necessary for those spending their life cycle inside the plant tissue and contact insecticides for those feeding externally during their early stage. Study reports have shown that chemicals have been effective in suppressing the population of stemborers. The study conducted by Cugala & Omwega (2000) in Mozambique, has shown that when insecticides are applied against *C. partellus* in maize, yield can increase two to four-fold.

The study also recommended applying diazinon twice into the whorl when the plants are 3 and 5 weeks old for effective control of this pest.

A single application of endosulfan was advantageous when applied shortly before tasselling and/or panicle emergence in grain sorghum. Placement of granular dusts of endosulfan, carbaryl, Malathion, or fenvalerate and bulldock in maize leaf whorls are effective against *C. partellus* (Kfir *et al*., 2002; Tomlin, 2009; Van Zyl, 2013 & Ateia, 2018).

The insecticide Furadan (Carbofuran) is effective as a seed treatment or after planting (1kg active ingredient/hectare). If serious leaf damage is observed, Furadan granules can be applied to the soil or can be dropped into the plant's funnel when the plants have six or seven leaves. Furadan is a systemic insecticide which is effective even after the larvae penetrate into the stem. Non-systemic insecticides like Sevin or Lindane control stem borers only if applied before the larvae begin boring into the stem

Above all, the time, rates and frequencies of applications of any kind of spray is vital because stem borers are difficult to control with insecticides. The reason is that existing spray-based practices have been found ineffective against internal feeders. Spraying should be done before the moths lay their eggs or when larvae are at their most vulnerable stage (feeding at the base of the leaves) or before most larvae tunnel into stalk.

2.8.5 Integrated pest management

Although control of *C. partellus* using synthetic insecticides is far more effective, chemicals are uneconomical for many resource-poor small-scale farmers of Africa

(Valencia *et al*., 2006). In addition, due to the cryptic feeding behavior of mature larvae repeated pesticide applications may be required. Moreover, pesticides may also kill its natural enemies and other beneficial insects. For instance, in Pakistan managing this pest using chemicals increase the pest population and causes 43.3% yield loss due to killing of natural enemies (Emana Getu, 2007; Khan *et al*., 2015 & Cugala *et al*., 2006). In such scenario, the usual pest control option consists of cultural control measures that are mainly concerned with the reduction of carry-over of pests from one crop cycle to the next (Neuenschwander *et al*., 2003).

Botanicals are considered environmentally friendly. This method not only reduces applications of chemical insecticides but also the cost of pest management, which is an important factor for farmers in developing countries. The uses of biocontrol agents in pest management are effective as they are economical, ecofriendly and compatable with other pest control options. Thus, in order to minimize the use of hazardous chemical pesticides and to manage this pest attack as well as to increase the crop productivity it is necessary to implement integrated pest management (IPM) options as they have little side effect on natural enemies of insect pests (Akob & Ewete, 2007; Emana Getu, 2007 & Khan *et al*., 2015). IPM is the use of more pest control methods including cultural, sanitation, botanicals, biological and other non-chemical methods with the use of little pesticides (Swarwar, 2015). IPM is environmentally safe, economically feasible and acceptable to resource limited farmers.

Chapter 3

Status of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) and its damage levels on different growth stages of sorghum and wild host plants

3.1 Introduction

Chilo partellus (Swinhoe) is an exotic stemborer introduced to Africa from Asia some eighty years ago (Emana Getu *et al*., 2001; Le Ru *et al*., 2006 & Hutchison *et al*., 2008). After arriving in Africa it has rapidly spread over a wide geographical range and has proven to be a very efficient colonizer and devastating pest whenever it occurred (Kfir, 1997; Nedmhan *et al*., 2007; Amanuel Tamiru *et al*., 2012 & Mutamiswa *et al*., 2017). In Ethiopia, the pest has distributed to the lower elevation of the major sorghum growing areas. However, its distribution appears to be expanding to the higher elevation and increased its share of the total borer population every year (Emana Getu *et al*., 2001; Melaku Wale *et al*., 2006; Amanuel Tamiru *et al*., 2007; Asmare Dejen *et al*., 2013 & Yonow *et al*., 2017).

C. partellus is now the most important problem for sorghum growers in South Wollo and Oromia zone of Amhara region. The pest attacks all stages (from seedling to maturity) of sorghum and several wild host plants. *C. partellus* initial damage is caused by the feeding of neonate larvae on the leaf tissues causing leaf injuries, followed by tunneling and feeding within the stem. When infestation is severe, larvae feed through the central leaves and destruct the growing points to produce ‘dead heart’ symptom, resulting in the death of the plant. The late third or early fourth instars bore into the stem, feeding on tissues and making tunnels. Extensive tunneling inside the stems weakens the plants causing

breakage and lodging (Tadele Tefera, 2004; Moonga, 2007; Emana Getu *et al*., 2008 & ISU, 2012) resulting in maximum yield loss during harvesting.

Although, *C. partellus* attack sorghum and several wild host plants in the country, its status is expected to vary with different hosts, sorghum growth stages and locations. Therefore, this study was carried out in an attempt to obtain the current situations of this pest on different stages of sorghum and wild hosts. The aims of this study were:

- to recognize the distribution and abundance of *C. partellus* at all growth stages of sorghum and wild hosts in Kalu, Bati and Dawa Chefa districts of Amhara Region
- to assess the incidence and damage of *C. partellus* at the different growth stages of sorghum and wild host plants in Kalu, Bati and Dawa Chefa districts of Amhara Region

3.2 Material and Methods

3.2.1 Description of the study area

The study was conducted in north eastern Ethiopia, South Wollo and Oromia zone of Amhara region in three districts: Kalu, Bati and Dawa chefa (Figure 3.1). These districts were the major sorghum growing areas and *C. partellus* is the most important species limiting sorghum production. Survey sites were selected purposively based on high production of sorghum and availability of *C. partellus*. Survey data were used to estimate the abundance of the pest using geographical information system (GIS). A global positioning system (GPS) was used to record the latitude, longitude and elevation of the

surveyed sites. Annual rainfall, temperature, humidity and elevation data were obtained from the Ethiopian Metrological Authority and the internet (Table 3.1).

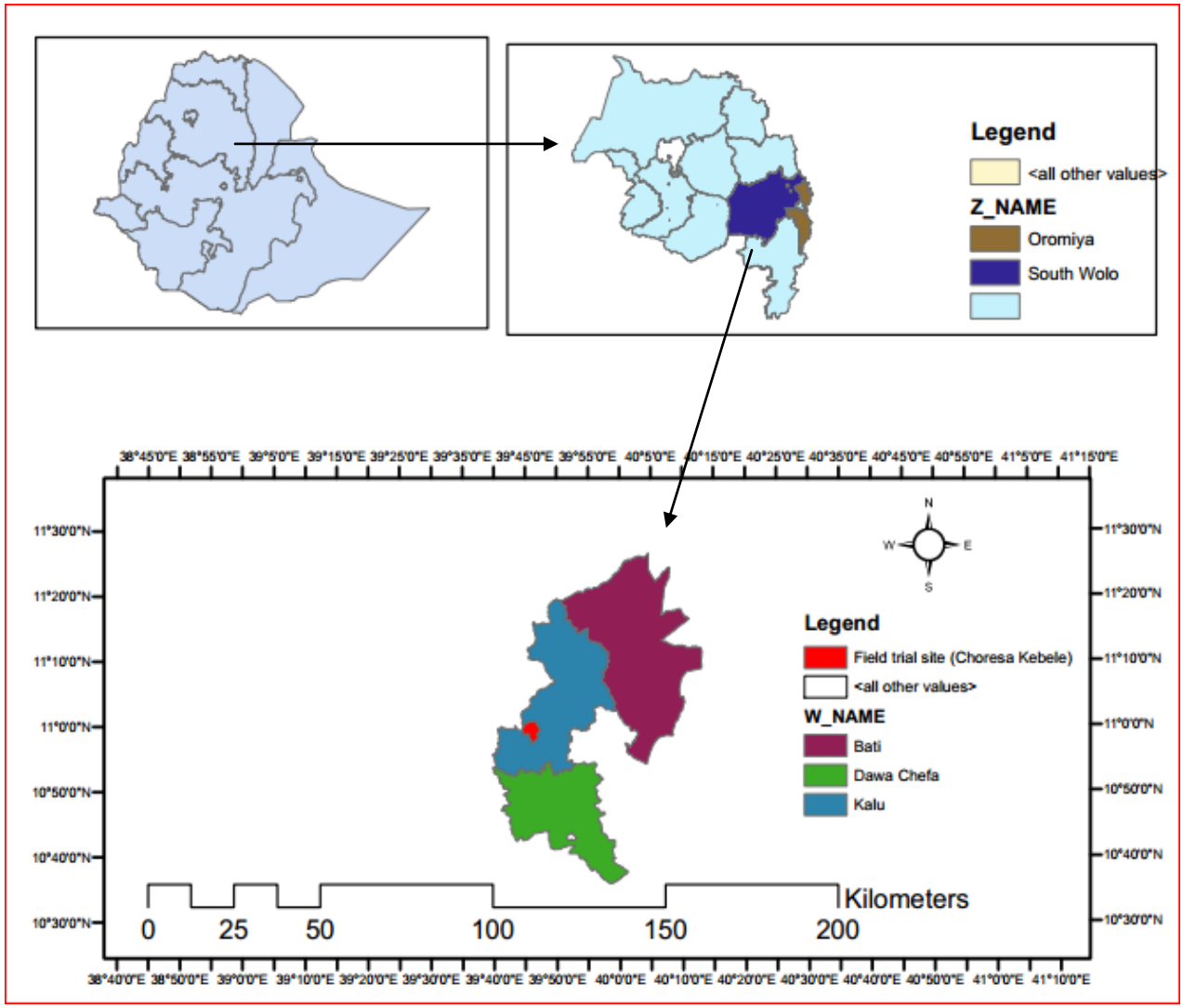

Figure 3.1 Map showing survey sites at regional, zonal and district levels using ArcGIS 10

Climate

Ecologically, the study areas are found in north-east direction in warmer low altitude (Kola) zones, which represent an arid and semi arid ecology receiving a long dry period.

Rainfall in these districts were highly variable and thus, generally bi-modal in distribution.

Topographic condition (elevation and geo-position)

Kalu is located in South Wollo, while Bati and Dawa Chefa are in Oromia special zone of Amhara National Regional State. Kalu and Dawa Chefa are 375 and 325 km far away from Addis Ababa, in the north east direction, respectively. Bati is about 415 km far from Addis Ababa in the east direction. Geographically Kalu, Dawa Chefa and Bati districts located at 39^0 43' É, 11^0 6'N, 39^o 48'E, 10^o 51'N and 39^0 59'E, $11^0$11'N longitude and latitude, respectively.

Table 3.1 Elevation (m), temperature (^{0}c), relative humidity (%) and rainfall (mm) of each locality in 2016/17 & 2017/18

Zones	Districts	Kebeles	Elevation	Annual Rainfall	Temperature Max.	Min	Mean relative Humidity
South Wollo	Kalu	Galesa	1859	1426.4	24.6	11.3	71.0
		Degan	1497	1225.8	31.8	12.8	65.2
		Chorissa	1675	1313.5	26.3	13.2	73.3
Oromia	Bati	Birra	1459	1183.0	28.3	13.8	67.2
		Kuni	1412	1183.0	28.3	13.8	67.2
		Albuba	1464	1127.3	29.5	14.0	67.2
	Dawa Chefa	Shekla	1629	1027.3	29.9	12.7	60.3
		Woledi	1529	1027.3	29.9	12.7	64.0
		Gode	1446	1375.2	30.7	14.6	55.7

Source: Ethiopian metrological authority and internet

3.2.2 Study design and sampling procedure

Field surveys were conducted on sorghum and wild host plants over two years during the long rainy season of June 2016/17 to December 2017/18. In the surveys, sorghum fields

and indigenous host plants growing around and/or at field margins were examined for possible infestation of *C. partellus* as follows:

Surveys in sorghum field

To determine the abundance and incidence of *C. partellus* a destructive sampling method was used. Nine sorghum fields having similar variety and sowing dates were selected for sampling in 3 districts. All fields were sampled at all growth stages (from seedling to maturity) of the plant. Levels of infestations were estimated from 60 randomly selected sorghum plants per field. Twenty (20) of the 60 sampled stalks were randomly inspected by walking from the top left corner diagonally to bottom right corner of the field, and the other 20 samples were from the top right corner diagonally to the bottom left corner. The remaining 20 were inspected by walking through the center of the field from top to bottom and side to side. The plant stems were split open using knife from the base to the apical end to expose the larvae. Altogether, 180 sorghum stems were dissected from each site in the similar manner. Relative abundance of *C. partellus* was determined as the total number of *C. partellus* found expressed as the percentage of the total population of all stem borer species found at each district. Percent infestation and relative abundance of each stem borer were calculated as outlined by Emana Getu *et al*. (2001) below:

$$\text{Percent infestation} = \frac{\text{total number of plants infested}}{\text{total number of plants}} \times 100$$

$$\text{Relative abundance (\%)} = \frac{\text{number of individual stem borer species}}{\text{total number of all stem borer species}} \times 100$$

Leaf damage and dead hearts at seedling and vegetative stages were assessed before destructive sampling. This was done by scoring damage on leaves using a scale of 1-5 on five randomly selected plants based on the amount of feeding on the four uppermost leaves (rating scale: 0=no leaf damage, 1=1-20% leaf damage, 2=21-40% leaf damage, 3=41-60% leaf damage, 4=61-80% leaf damage, 5=81-100% leaf damage). The rating scale was adopted from Kalule *et al*. (1997). At vegetative, heading and maturity stages the extent of damage was assessed by measuring the length of tunnels using a 30 cm ruler on the interior of the dissected plants. Prior to splitting the stem, the number of holes created by stem borer feeding on all the stalks were counted and recorded.

Surveys in wild host plants

Since densities of borer on wild hosts are considerably lower than in adjacent cultivated plants (Gounou and Schulthess, 2004; Le Ru *et al*., 2006; Matama-Kauma *et al*., 2008 & Mailifiya *et al*., 2009) selective sampling method was adopted to increase the chance of finding stem borers. In surveying wild host plants growing around or on field margins (near by sorghum crops) attentions was given to host plants belonging to the Poaceae family. Depending on the access, 20-100 plants were collected and inspected for borers. Wild host plants with stem borer damage symptoms were collected and reserved for identification. All borers found were treated as described above.

Wild hosts' identification

Wild host plants with stem borer damage symptoms were identified to species level at Addis Ababa University Science Faculty, National Herbarium. Ethiopia.

Rearing stem borers for identification

Field collected stem borers were brought to the kombolcha plant health clinic laboratory for rearing to a later life stage to facilitate identification (Plate 4.1). Small larvae were reared on whorl materials and then placed on sorghum stems once they become third instars. Stemborer species were identified to species level using identification keys, color pictures and morphometric method with reference to the key developed by Overholt *et al*. (2001). Larvae were identified on the base of body pigmentation and abdominal crochets to species level. *C. partellus* larvae have a cream to pink coloration, with dark spots along the dorsal surface; the head capsule is brown. *C. partellus* larvae can be distinguished from *B. fusca* by the presence of a complete circle crochets on the prolegs whereas in *B. fusca* the crochets are arranged in a crescent (Hutchison *et al*., 2008).

Data analysis

Data were analyzed using SPSS Version 16 software. Significant means ($P<0.05$) were separated using Least Significance Difference (LSD). Data deviated from normality were transformed using square root (x+0.5) transformation before analysis. Average leaf damage scores, incidence of *C. partellus*, density, infestation, tunnel length and number of holes were summarized in the form of table and graphs using SPSS software and Microsoft Excel.

3.3 Results

3.3.1 Presence or absence of stem borers on cultivated and wild host plants

The presence or absence of stem borer species that were examined in different host plants from different study sites is presented in Table 3.2. *C. partellus* is dominantly recorded from all districts on sorghum. *C. partellus* larvae were recorded on *P. purpureum and P. maximus* from all districts. *C. partellus* larvae also recorded on *E. corocana* and *H. rufa* from Kalu and Dawa Chefa districts, respectively.

Table 3.2 Plant species examined for the presence or absence of stem borers in different districts, 2016/17 & 2017/18

Locality	Host plant species	*C. partellus*	*B. fusca*	*S. alamistis*
Kalu	*Sorghum bicolor*	+	+	+
	Hyparrhenia rufa	-	+	-
	Pennisetum purpureum	+	+	-
	Eleusine corocana	+	+	-
	Panicum maximum	+	+	-
Bati	*Sorghum bicolor*	+	+	-
	Hyparrhenia rufa	-	-	-
	Pennisetum purpureum	+	-	-
	Eleusine corocana	-	+	-
	Panicum maximum	+	-	-
Dawa chefa	*Sorghum bicolor*	+	-	-
	Hyparrhenia rufa	+	+	-
	Pennisetum purpureum	+	+	-
	Eleusine corocana	-	-	-
	Panicum maximum	+	-	-

+, recorded as presence, -, not recorded or recorded as absence

3.3.2 The status of *C. partellus* on sorghum and wild host plants during 2016/17 & 2017/18

A total of 374 and 352 *C. partellus* larvae were collected from sorghum in 2016/17 & 2017/18, respectively. Of the total stem borers collected, the Crambidae *C. partellus* account for 90.3% and 91.2% in 2016/17 and 2017/18, respectively. The highest number of *C. partellus* was recorded from Bati and the lowest was from Kalu (Table 3.3).

A total of 5 and 9 *C. partellus* larvae were collected from 540 wild host plants in 2016/17 and 540 in 2017/18, respectively. *C. partellus* was the dominant stem borer species accounting for 45.4% in 2016/17 and 69.2% in 2017/18 on wild host plants.The highest number of *C. partellus* larvae was recorded from Kalu although; it was recorded as a dominant stemborer species in Bati and Dawa Chefa districts on wild host plants (Table 3.3).

Table 3.3 Total number of stem borer species recorded on sorghum and wild host plants during 2016/17 & 2017/18 crop growing seasons

Total recorded species											
		Cultivated host					Wild host				
Study sites (Districts)	Year	No. borer recovered	Cp	Bf	Sc	(%) Cp	No. borer recovered	Cp	Bf	Sc	(%) Cp
Kalu	2016/17	105	73	27	5		7	3	4	0	
	2017/18	117	86	31	0		6	3	3	0	
Bati	2016/17	169	161	8	0		2	1	1	0	
	2017/18	121	118	3	0		2	2	0	0	
Dawa Chefa	2016/17	140	140	0	0		2	1	1	0	
	2017/18	148	148	0	0		5	4	1	0	
	2016/17	total	374			90.3	total	5			45.4
	2017/18		352			91.2		9			69.2

Cp = *C. partellus*, Bf = *B. fusca*, Sc = *S. calamists*

C. partellus was dominantly recorded from all study areas on cultivated sorghum. The only stem borer species collected from Dawa Chefa district was *C. partellus* (Table 3.4). However, on wild host plants it was dominantly recorded from Bati followed by Dawa Chefa districts, the lowest was recorded from Kalu (Table 3.4).

Table 3.4 Stem borer species composition and *C. partellus* abundance on cultivated and wild host plants 2016/17 & 2017/18 (pooled data over years)

Dominance (%)						
	Cultivated host			Wild host		
Study sites	*C. partellus*	*B. fusca*	*S.calamistis*	*C. partellus*	*B. fusca*	*S.calamistis*
Kalu	71.6	26.1	2.3	46.1	53.8	0
Bati	96.2	3.79	0	75.0	25.0	0
Dawa Chefa	100	0	0	71.4	28.5	0

3.3.3 Abundance of *C. partellus* at the four plant growth stages of sorghum crop

Number of *C. partellus* differed significantly among different growth stages of sorghum crop and districts. *C. partellus* abundance was recorded the highest (1.13) from Bati followed by Dawa Chefa district at seedling stages and the lowest was (0.78) recorded at this stage from Kalu. The recorded number of *C. partellus* larvae was the lowest in all the districts at maturity stage of sorghum (Tables 3.5).

Table 3.5 Mean (±SE) abundance of *C. partellus* on different growth stages of sorghum during, 2016/17 & 2017/18 (pooled data)

Districts	Plant growth stages	Cp	Bf	Sc
Kalu	Seedling stage	0.78±0.00^{d}	0.81±0.01^{ab}	0.71±0.0^{b}
	Vegetative stage	0.92±0.04^{b}	0.72±0.01^{d}	0.71±0.0^{b}
	Heading stage	1.05±0.02^{a}	0.77±0.03^{c}	0.72±0.01^{ab}
	Maturity stage	0.85±0.01^{c}	0.83±0.02^{a}	0.72±0.04^{a}
	Levels of significant	**	**	NS
	LSD at .05	0.06	0.04	0.04
Bati	Seedling stage	1.13±0.01^{a}	0.71±0.0^{c}	0.71±0.0
	Vegetative stage	1.02±0.01^{abc}	0.71±0.0^{c}	0.71±0.0
	Heading stage	1.08±0.01^{ab}	0.72±0.01^{ab}	0.71±0.0
	Maturity stage	0.89±0.00^{c}	0.75±0.02^{a}	0.71±0.0
	Levels of significant	**	NS	-
	LSD at .05	0.14	0.04	-
Dawa chefa	Seedling stage	1.12±0.03^{a}	0.71±0.0	0.71±0.0
	Vegetative stage	1.05±0.01^{bc}	0.71±0.0	0.71±0.0
	Heading stage	1.08±0.01^{ab}	0.71±0.0	0.71±0.0
	Maturity stage	0.92±0.04^{d}	0.71±0.0	0.71±0.0
	Levels of significant	**	-	-
	LSD at .05	0.06	-	-

Means in a column followed by the same letter are not significantly ($P \leq 0.05$) different from each other, (LSD). Cp = *C. partellus*, Bf = *B. fusca*, Sc = *S. calamists* **= Significant NS= Not significant

C. partellus was recorded as the only stem borer species from Dawa Chefa district with the relative abundance of (100%). However, it was recorded as the dominant stem borer species from Bati with the relative abundance of (58.8%). The relative abundance of *C. partellus* was low (37.5%) at Kalu (Table 3.6).

Table 3.6 Relative abundance (%) of *C. partellus* on sorghum

Location	Stem borers recovered	Total number of stem borers per district	Relative abundance of stem borers
Kalu	*C. partellus*	3.6	37.5
	B.fusca	3.13	32.6
	S. calamistis	2.86	29.8
	Total	9.59	99.9
Bati	*C. partellus*	4.12	58.8
	B.fusca	2.89	41.2
	Total	7.01	100
Dawa chefa	*C. partellus*	4.17	100
	Total	4.17	100

3.3.4 Abundance of *C. partellus* on different wild hosts in 2016/17 & 2017/18 cropping seasons

Abundance of *C. partellus* is not significant among different wild hosts and localities. The highest (0.716±0.0) number of *C. partellus* was recorded from Dawa Chefa on *P. maximum*, followed by *P. purpureum* (0.715±0.003) from Kalu. The lowest number (0.711±0.001) was recorded on *E. corocana* and *P.maximum* from Kalu, and *H.rufa* from Dawa Chefa districts. *C. partellus* was not recorded on *H.rufa* from Kalu and Bati and on *E. corocana* from Bati and Dawa Chefa districts (Tables 3.7).

Table 3.7 Mean (±SE) *C. partellus* abundance on different wild hosts in 2016/17 & 2017/18 (pooled data)

Districts	Wild host plants	Cp *(*Mean)	Bf *(*Mean)
Kalu	*Hyparrhenia rufa*	0.710±0.000[b]	0.711±0.001[a]
	Pennisetum purpureum	0.715±0.003[a]	0.715±0.003[a]
	Eleusine corocana	0.711±0.001[b]	0.711±0.001[b]
	Panicum maximum	0.711±0.001[c]	0.714±0.004[a]
	Levels of significant	NS	NS
	LSD at .05	0.0	0.0
Bati	*Hyparrhenia rufa*	0.710±0.0[c]	0.710±0.0[b]
	Pennisetum purpureum	0.711±0.001[b]	0.710±0.0[b]
	Eleusine corocana	0.710±0.0[c]	0.711±0.001[a]
	Panicum maximus	0.714±0.004[a]	0.710±0.0[b]
	Levels of significant	NS	NS
	LSD at .05	0.0	0.0
Dawa chefa	*Hyparrhenia rufa*	0.711±0.0[a]	0.711±0.001[a]
	Pennisetum purpureum	0.712±0.0[a]	0.711±0.001[a]
	Eleusine corocana	0.710±0.0[b]	0.710±0.0[b]
	Panicum maximum	0.716±0.0[a]	0.710±0.0[b]
	Levels of significant	NS	NS
	LSD at .05	0.0	0.0

Means in a column followed by the same letter are not significantly ($P \leq 0.05$) different from each other, (LSD). Cp = *C. partellus*, Bf = *B. fusca*, Sc = *S. calamists* **= Significant NS= Not significant

C. partellus was recorded as the dominant stem borer species from Dawa Chefa district with the relative abundance of (50%). However, the number was not statistically different from Bati. The relative abundance of *C. partellus* was low (49.9%) at Kalu (Table 3.8).

Table 3.8 Relative abundance (%) of *C. partellus* on wild host plants

Location	Number borers recovered	Total number per district	Relative abundance (%)
Kalu	*C. partellus*	2.847	49.9
	B.fusca	2.851	50.0
	Total	5.698	99.9
Bati	*C. partellus*	2.844	50.03
	B.fusca	2.841	49.97
	Total	5.685	100
Dawa chefa	*C. partellus*	2.848	50.05
	B.fusca	2.842	49.94
	Total	5.690	99.9

3.3.5 Relative abundance of *C. partellus* on cultivated and wild hosts in 2016/17 & 2017/18 cropping seasons

The relative abundance of *C. partellus* differed significantly among different host plant species and localities. Hundred percent (100%) relative abundance of *C. partellus* was recorded from Dawa Chefa on sorghum. The lowest was recorded from Kalu. Relatively high number of larvae was recorded from Bati (50%) on wild host plants however; this was not significant from Dawa Chefa. The lowest (49.9%) was recorded from Kalu (Figure 3.2).

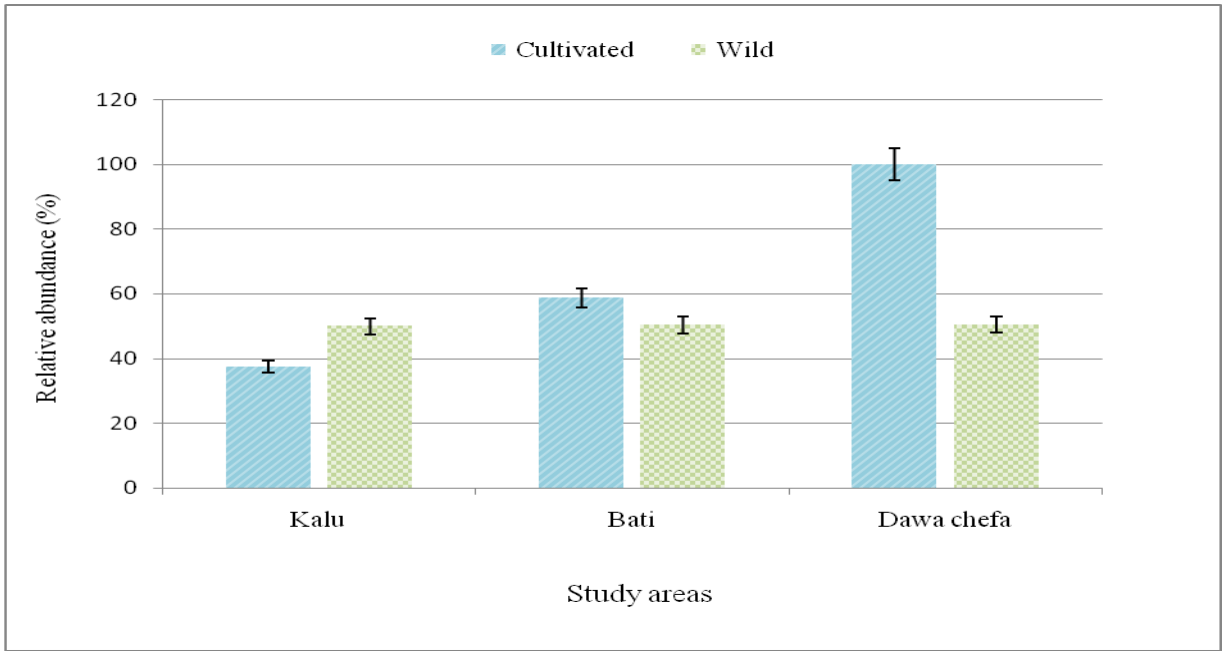

Figure 3.2 Relative abundance (%) of *C. partellus* on sorghum and wild host plants

3.3.6 *C. partellus* density on sorghum at different growth stages and on wild hosts

Density of *C. partellus* was statistically different in all the locations and on all the growth stages. High mean number of *C. partellus* larvae per plant was recorded from all districts with the highest from Bati and Dawa Chefa districts on sorghum. The lowest was recorded from Kalu (Figure 3.3). Density was also significantly different across sorghum plant growth stages. The highest larvae per plant (5.02±0.53) were recorded at seedling from Bati. The lowest number of larvae/plant (1.66±0.23) was recorded at vegetative stage from Kalu. However, in all the areas high number of larvae per plant were recorded on sorghum at seedling and heading stages (Figure 3.3).

Larvae were recorded on wild host plants from all the districts. Large number of larvae per plant was collected from Kalu and Dawa Chefa districts (Figure 3.3). However, density on wild host plants was significantly different across the different hosts. The

highest larvae per plant (1.33±0.11) were recorded from Kalu on *P. purpureum.* The lowest larvae per plant were recorded on *H. rufa* and *E. corocana* (Figure 3.3).

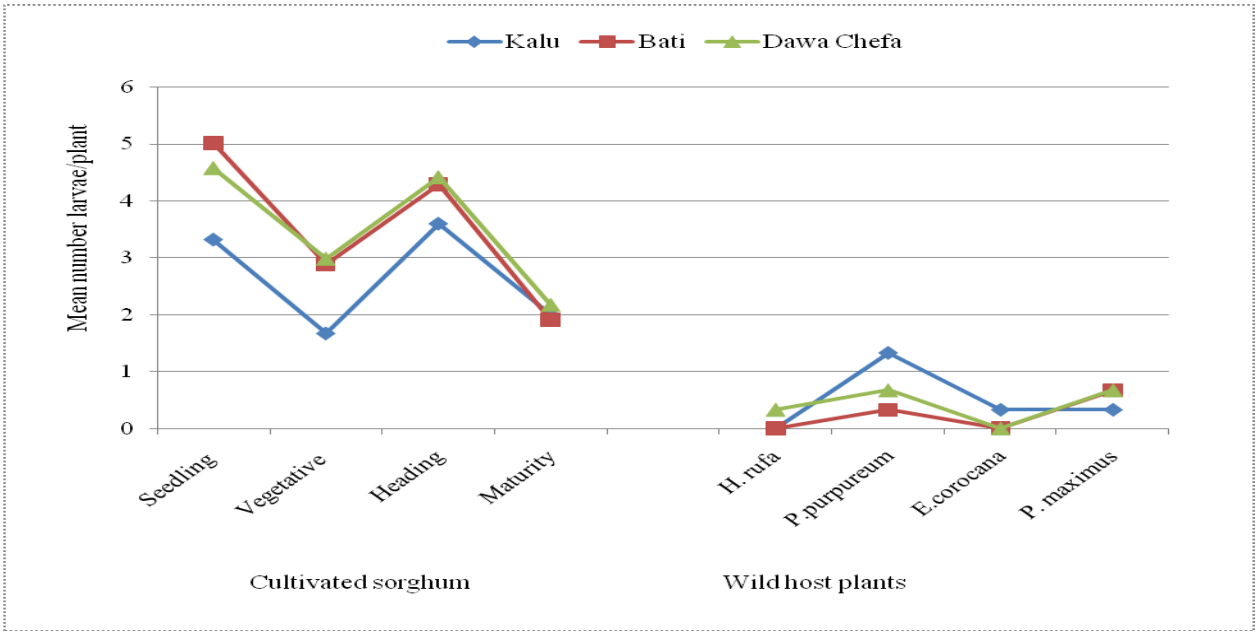

Figure 3.3 Mean (± SE) larval densities of *C. partellus* at different sorghum growth stages & wild host plants

3.3.7 *C. partellus* infestations at different growth stages of sorghum and wild host plants

The incidence of *C. partlleus* larvae was significantly different between different host plants and locations (Table 3.9 & 3.10). The mean numbers of *C. partellus* larvae ranged from 13.3-31.65 on sorghum across the locations with Kalu having had the lowest. Similarly, the mean numbers of *C. partellus* larvae ranged from 0.37-1.46 on wild host plants across the locations.

Infestation was significantly different among different sorghum growth stages, host plants and locations. High percent infestations were recorded on sorghum from Bati and

Dawa Chefa districts with the highest (31.67%) from Bati at seedling stages. The lowest (13.3%) was at vegetative stages from Kalu. However, infestations in Dawa Chefa were intermediate and varied between 25.0 to 30.0% (Table 3.9).

Table 3.9 Mean (± SE) *C. partellus* infestation (%) at different growth stages of sorghum (pooled data over years)

Hosts	Districts		
Sorghum	Kalu	Bati	Dawa Chefa
Seedling	26.67±4.4[a]	31.67±6.0[a]	30.00±5.7[a]
Vegetative	13.30±3.3[abc]	26.67±4.4[ab]	25.00±5.0[abc]
Heading	25.00±8.6[ab]	26.67±8.8[ab]	28.33±5.4[ab]
Maturity	20.00±10.0[abc]	18.33±8.3[abc]	26.67±8.8[abc]
LSD at .05	18.12	17.90	15.76

Means in a columun followed by the same letter are not significantly ($P \leq 0.05$) different from each other, (LSD).

On wild host plants the highest mean percent infestation (1.46%) was recorded from Kalu on *P. purpureum*. Infestation recorded on *P. maximus* was higher (0.73%) from Bati and Dawa Chefa. No infestations were recorded on *H. rufa* from Kalu and on *H. rufa* and *E.corocana* from Oromia districts (Table 3.10).

Table 3.10 Mean (± SE) *C. partellus* infestation (%) at different wild host plants (pooled data over years)

Hosts	Districts		
Wild plants	Kalu	Bati	Dawa Chefa
H. rufa	0.00±0.0[c]	0.00±0.0[b]	0.37±0.36[a]
P.purpureum	1.46±0.36[a]	0.37±0.36[a]	0.73±0.36[a]
E.corocana	0.37±0.36[b]	0.00±0.0[b]	0.00±0.0[b]
P. maximus	0.37±0.36[b]	0.73±0.36[a]	0.73±0.36[a]
LSD at .05	0.80	0.65	0.70

Means in a columun followed by the same letter are not significantly ($P \leq 0.05$) different from each other, (LSD).

3.3.8 *C. partellus* damage on sorghum plants at different growth stages

3.3.8.1 Leaf damage scores

Mean leaf damage scores at seedling stages were high with a range of between 0.65 & 1.15 across the locations. The highest scores were obtained from Bati, while the lowest were from Kalu district (Figure 3.4). Similarly, all districts were statistically significant (F=34; d.f. = 2; P<0.000)

The leaf damage scores at vegetative stages were ranging between 0.45 & 0.75. The highest scores were obtained from Bati, while the lowest were from Kalu district. However, the difference between the two stages was not statistically different (F=3.9; d.f.= 2; P = 0.08) (Figure 3.5).

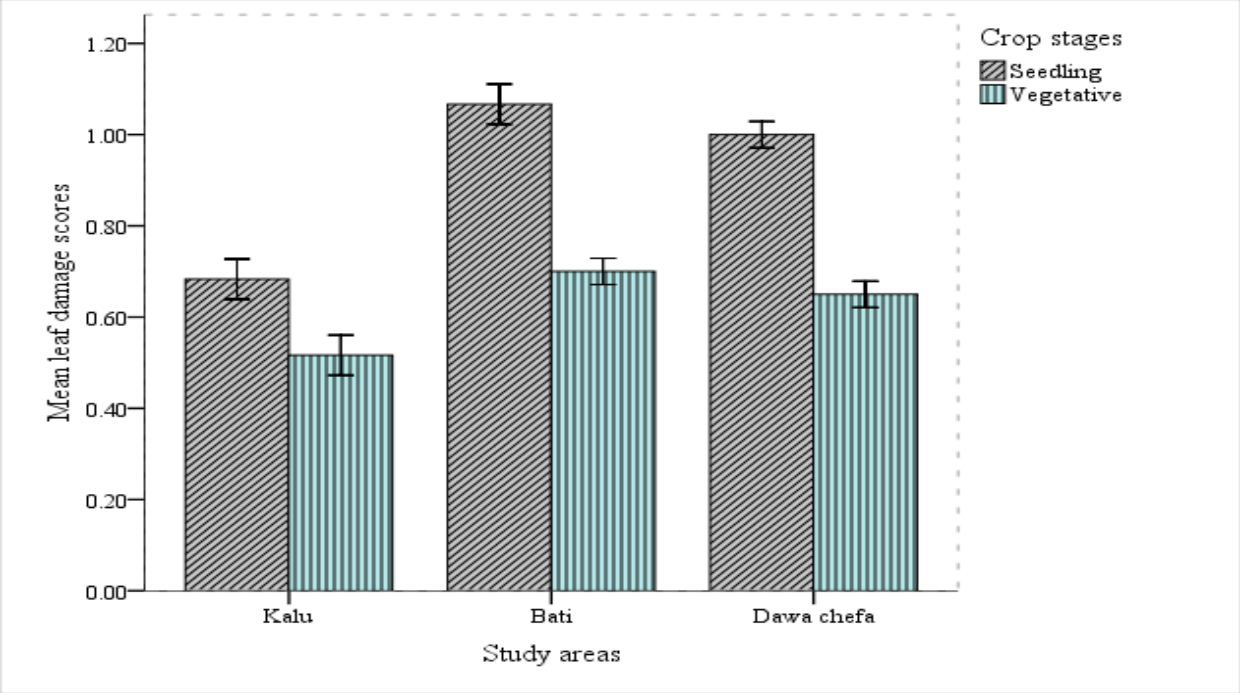

Figure 3.4 Mean leaf damage score across the three locations

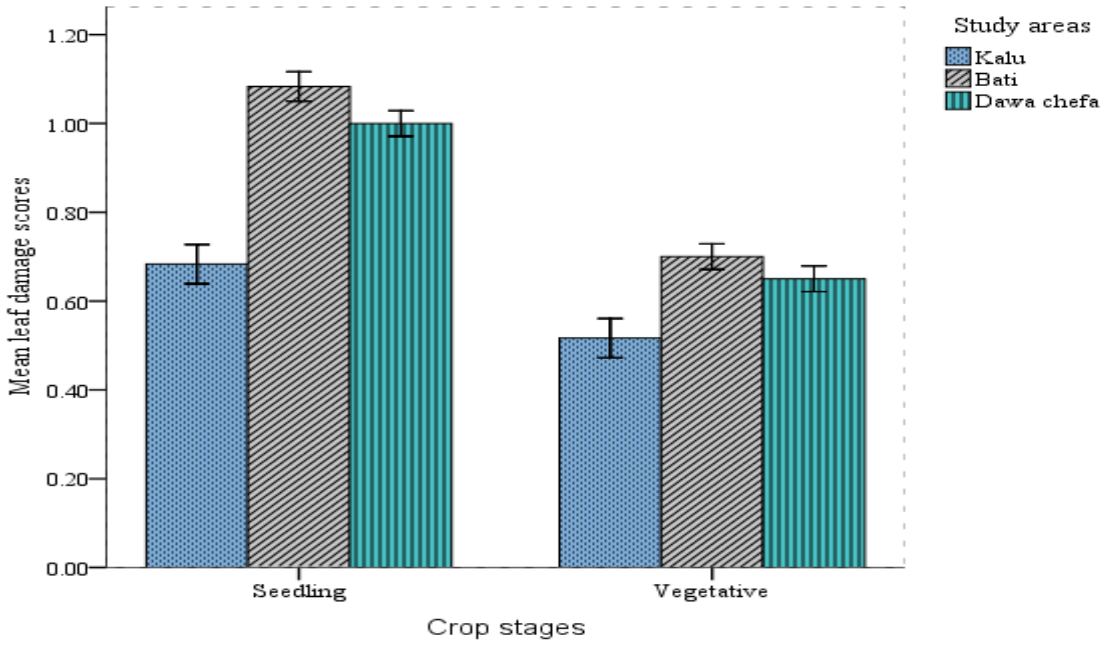

Figure 3.5 Mean leaf damage score at two growth stages across the three locations.

3.3.8.2 Exit holes due to *C. partellus*

There were variations in the mean number of exit holes across the districts at the three plant growth stages. Plants in Bati location had a high number of exit holes when compared to the other two locations (Figure 3.6). The difference in the number of exit holes at all stages in all locations were significant ($F=10.65$; d.f.=2; $P < 0.01$).

High number of exit holes was recorded in sorghum stems in all locations at maturity stages with the highest at Bati district (Figure 3.7). However, the number of holes in Dawa Chefa district was not statistically different from Kalu district. The lower exit holes were recorded at vegetative stages in all the districts with the lowest at Kalu. There were

significance differences in the number of exit holes made on sorghum stems across the locations at vegetative stage (F= 24.75; d.f.=2; P<0.001).

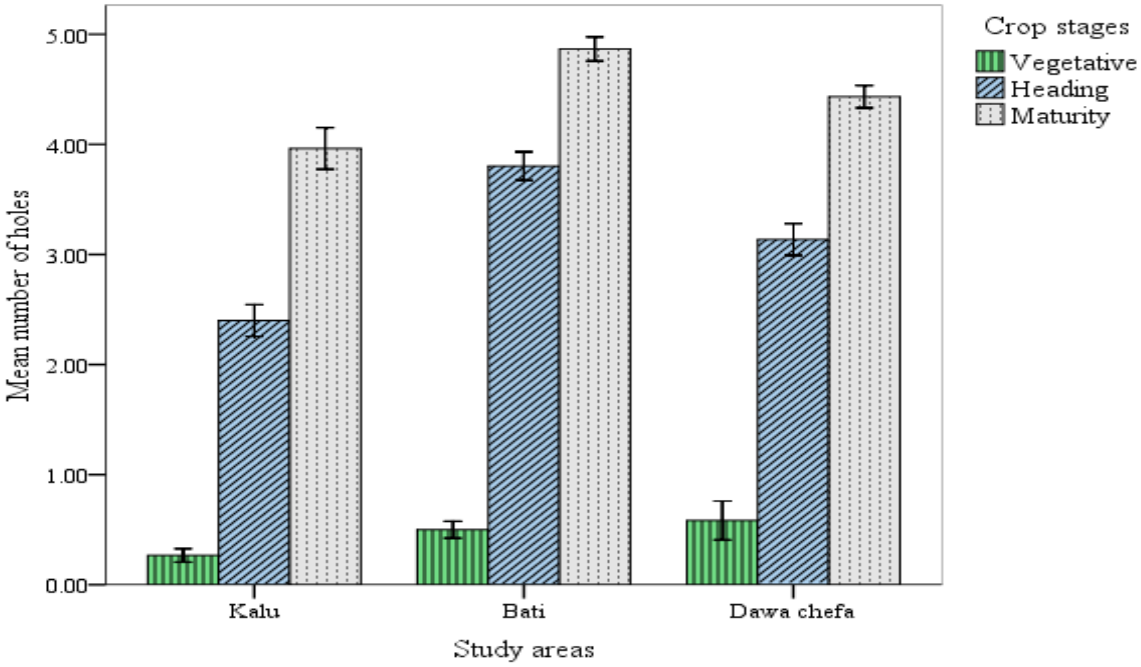

Figure 3.6 Mean number of holes across the three locations

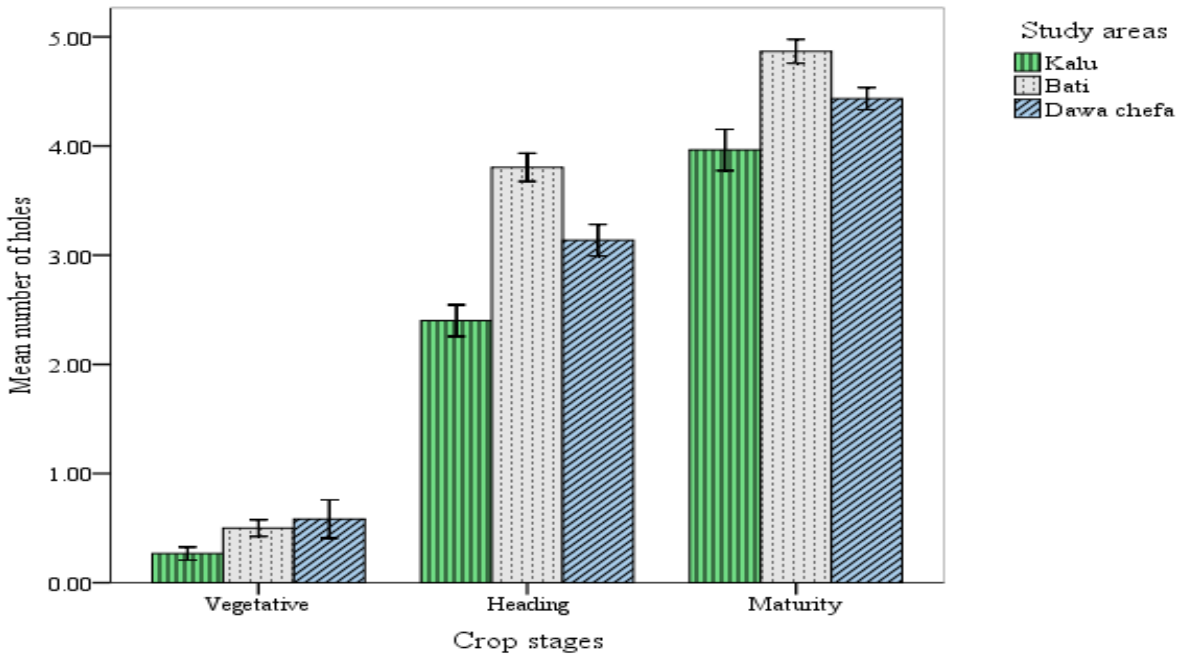

Figure 3.7 Mean number of holes at the three growth stages across the three locations.

3.3.8.3 Tunnel length made by *C. partellus*

Mean plant tunnel length due to *C. partellus* were observed at all the locations. However, Kalu had a significantly longer tunnel length at maturity stage when compared to the other locations (Figure 3.8). Variations in mean tunnel length across all the locations at maturity stage were significant (F=9.7; d.f.2; P=0.01).

Plants at the maturity stages had generally the longest mean tunnel length as compared to the vegetative stage. The shortest was observed from Kalu at the vegetative stage. However, variations in mean tunnel length in all the locations at vegetative stage were significant (F=18.02; d.f. 2; P < 0.002). Statistically significant variations (F= 0.11; d.f.= 2; P= 0.89) in the mean tunnel length were not observed across the three plant growth stages (Figure 3.9).

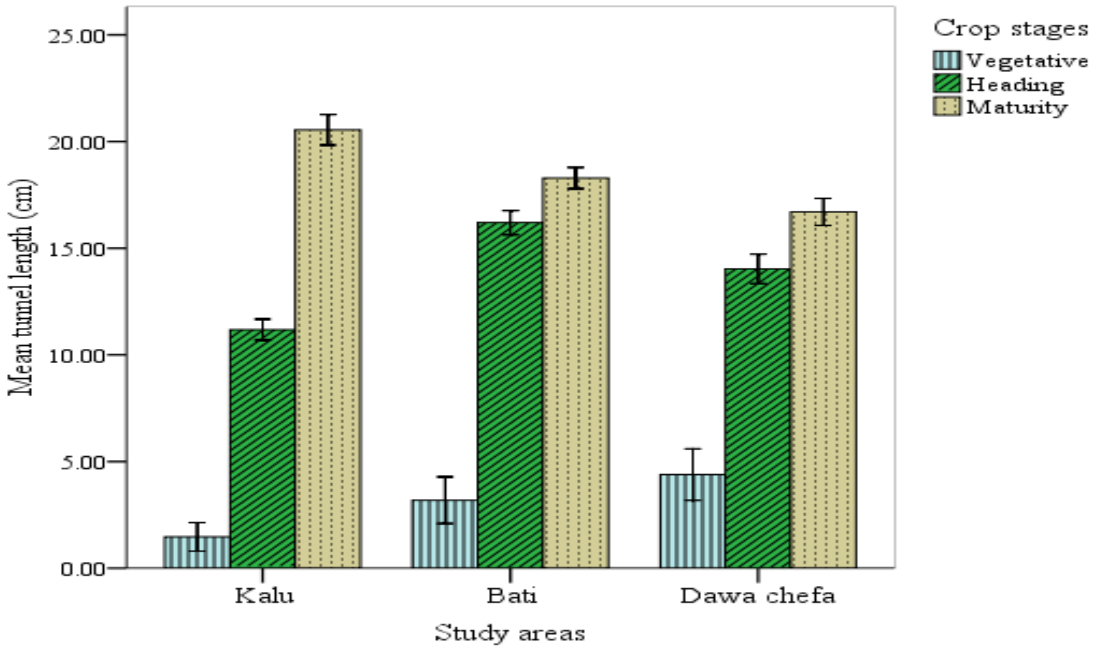

Figure 3.8 Mean tunnel length (cm) across the three locations

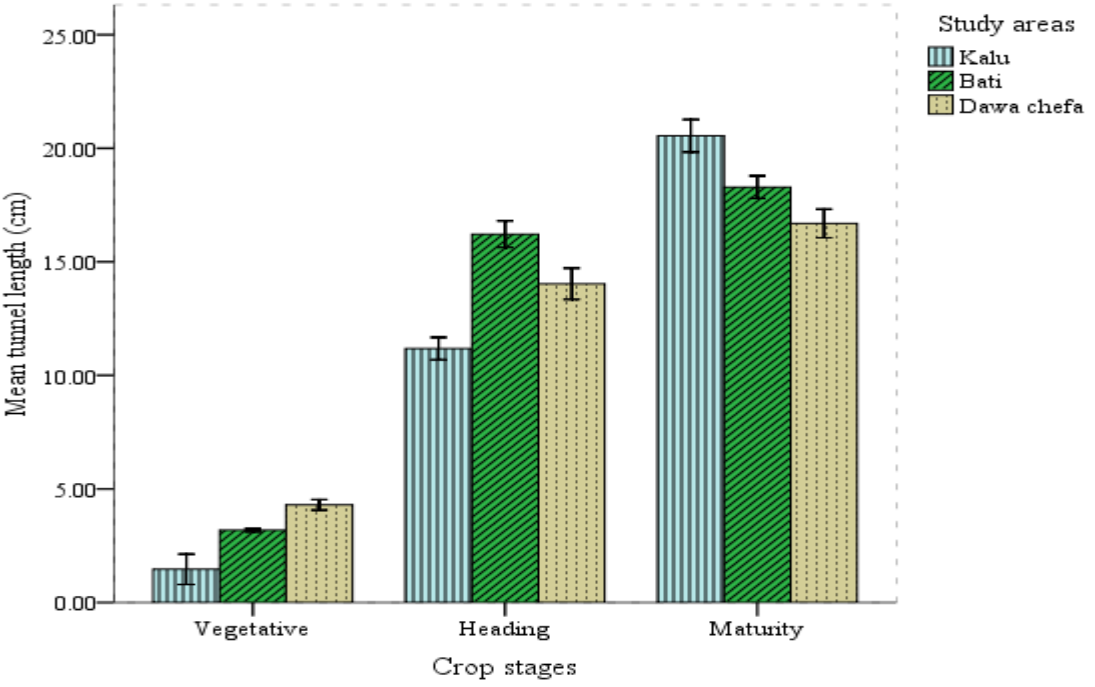

Figure 3.9 Mean tunnel length (cm) across the three sorghum growth stages

3.4 Discussion

In the surveys, *C. partellus* and *B. fusca* were the major stem borer species recorded on sorghum and wild hosts. *S. calamistis* was also observed on sorghum at Kalu in 2016/17 in low density. Of these species, *C. partellus* was the dominant species in all the surveyed areas at elevation ranging from 1412-1859 m a.s.l. Simillar species composition of stem borers were observed on wild hosts in all districts. *C. partellus* shared the maximum percent of the species complex in Bati and Dawa Chefa districts than South Wollo zone. This variation in these zones might be distribution of *C. partellus* is highly influenced by altitudinal differences, thus its percent share increases as the altitude decreases and vice versa. In line with the current result Emana Getu *et al*. (2001) reported the dominance of *C. partellus* at an altitude below 1700 m a.s.l. In this study the proportion of *C. partellus* increased from 71.6 to 100% following the drop of elevation and temperature rise confirming the distribution of *C. partellus* is negatively corelated to elevation and positively correlated to temperature. Simillarly, several studies reported that *C. partellus* distribution is influenced by a combination of climatic factors such as temperature, rainfall and humidity, with temperature being the most important (Emana Getu, 2002; Emana Getu *et al*., 2002; Melaku Wale *et al*., 2006; Amanueal Tamiru *et al*., 2007; Thomson *et al*., 2010 & Mutamiswa *et al*., 2017).

The current result clearly indicated that C. *partellus* was abundant at the early stages of sorghum in all districts. However, higher (58.8 and 100%) relative abundance were recorded from Bati and Dawa Chefa districts, respectively. The relative abundance of this pest was low (37%) at Kalu. The differences among the results might be due to the

environmental condition or the populations' pressure of other species. Among the different stem borers, *C. partellus* was the most dominant species on wild host plants with higher relative abundance at Bati and Dawa Chefa. The reason may be that this pest was the only and the dominant in utilizing a diverse range of hosts more than other species in these areas. This result is in agreement with the studies of Overholt *et al*. (1997), Ofomata *et al*. (2000), Songa *et al*. (2002), Le Ru *et al*. (2006) and McGeoch *et al*. (2004) who reported that *C. partellus* was dominantly found on several wild hosts than other stemborer species. Significantly very low numbers of larvae were recorded from wild hosts as compared with the cultivated sorghum. This implies that the host preference of the pest was cultivated sorghum that produce continuous availability of resources and possesses nutrients essential for the pest such as sugar and amino acids than wild hosts.

In this study 1080 wild grasses from the family Poaceae were collected and dissected from all areas, but very small number of larvae was recovered. The reason might be due to the fact that wild hosts were less conducive to larval feeding and growth leading to low survival, implying that these plants were either of poor nutritional value or had an antibiotic effect on the larvae. Similar to this result, extremely low incidence of stem borer larvae in wild hosts was reported by Moolman (2011) who indicated that only 0.0067% of the most common wild host plant species showed signs of borer infestation. Shanower *et al*. (1993) also reported the poor host status of grasses who observed <10% larval survival on wild hosts as opposed to 20-30% on cultivated crops. Similarly, Atachi *et al*. (2005) reported 0.05% survival of *E. saccharina* as well as reduced fecundity on a common grass host species.

Larvae per plant were low on wild hosts at all the study sites. The lowest larvae per plant recorded on wild host plants might be owing to the production of certain antibiotics or antixenosis characteristics by the wild grasses unlike sorghum. Similar results were also reported by Delenesaw Yewhalaw *et al*. (2008) and Gounou & Schultes (2004) who reported that density of *C. partellus* on wild host plants was low mostly as a result of low survival of young instars. Higher larvae per plant on sorghum from Bati and Dawa Chefa districts might be because of competitive ability of the pest that displaces all the indigenous stemborers and it became in all places the sole pest of sorghum in the area. In all districts, the highest density was recorded from sorghum at seedling stage. However, the difference was not significant at heading stages. This high number of larvae per plant at seedling stages implies the highest number of neonate larvae was hatched from the eggs and primarily infests the plants at this stage. Hence, higher number of larvae was recorded on seedling than the rest of the stages of sorghum which is in close agreement with the report of Kumar (1993), Kioko *et al*. (1995) and Aziz *et al*. (2017).

In both cropping seasons, it was observed that *C. partellus* was found tobe the dominant stemborers species in all surveyed areas. However, the result showed that the incidences of *C. partellus* were affected by age of the plant. Number of larvae was highest at heading stages across the locations compared to other growth stages and the difference was significant. This implies that the host plant at this stage provide essential nutrients and protective shelter to the pest insect. These results agree with the findings by other authors' in other study areas who did similar work (Seshu Reddy *et al*., 1990; Bonhof, 2000; Ndemah *et al*., 2001; Emana Getu *et al*., 2002 & Moonga, 2007). Sorghum crops in all the study areas were highly infested by *C. partellus* as compared with the surrounded

wild host plants, probably due to the host preference of the pest. This result is agreed with the study of Michaud *et al*. (2007) and Matama-Kauma *et al*. (2008) who reported that *C. partellus* prefers sorghum over wild host plants.

However, infestations were differed with the different growth stages of sorghum. Among the different plant growth stages, percent infestations were the highest at seedling stage. Infestation at heading stage was at peak during both seasons and decreases at maturity. The possible reason for lower infestation at the late stages might be immature stages, eggs and larvae were exposed to various natural enemies and attacked at each stage particularly the larvae before entering into the stem. The other more interesting explanation could be the dominant natural enemy, the larval parasitoid; (*C. flavipes*) come to prefer 3rd and 4th instars to attack this host on mature plant. The result of this study is in agreement with Asmare Dejen *et al*. (2013) who reported that *C. partellus* caused high infestations in the early stages of sorghum. These levels of high infestations at seedling stages are also relatively similar to those observed by Aziz *et al*. (2017) in area where maximum level of infestations were recorded on young plants. Although lower infestation was recorded on wild host plants, it was higher from Kalu than the other sites where lower percent infestation on sorghum was recorded. This may be the high abundance of these host plants around sorghum fields that could reduce infestation due to the host preference of the pest as the pest pulled away by wild hosts from the main plant.

Damage was observed in the farmers' field ranging from slight leaf injury to stem tunnelling. High leaf damage on sorghum was recorded at seedling stages across the locations. The possible explanation for this may be large numbers of neonate larvae that

hatched from eggs and feed voraciously on the leaves before entering to the stem. The result is in accordance with DeGroote (2002) who reported that stem borers begin to feed on the leaves only, after hatching causing lesions or windows. Leaf damage was varied at the two sorghum growth stages across the locations in this study. The highest leaf damages were recorded on seedling than vegetative stages. In all the locations the damage on leaf at the seedling stages was higher. This variation may be due to the impacts of natural enemies on vegetative stages of the crop.

There were variations in the mean number of exit holes across the districts at the three plant growth stages. The highest was at the late stage and the lowest was at early stage of the crop growth in all districts. High numbers of exit holes at the late stage suggests that sorghum plant at this stage could be more susceptible to stem borer infestation by mature larvae compared to the other stages. Stem tunnelling is a good indicator of the degree of plant damage and thus, yield loss; the more extensive the tunnelling the higher the yield loss (Kalule *et al*., 1997). In the present study extensive damage by tunnelling into the sorghum plant stem varied at the three plant growth stages across the location. However, the longest mean tunnel lengths were observed at maturity stage in all locations.

The number of tunnels reflects the number of larvae that penetrated the stem while the extent of damage is reflected by the mean length of tunnel. Tunnel length is a measure of susceptibility because the borers feed better on susceptible plant stages causing the long tunnels while the tunnels are shorter in the stages that are tolerant. The mean tunnel length was highest at maturity stage followed by heading and vegetative. This might be because this stage of the plant is more susceptible, nutrient rich and is suitable for the

larvae development while, heading and vegetative showed some level of acceptance to the pest. Despite a higher incidence of *C. partellus* larvae recorded on the heading stages more damage was observed at the maturity stages as it was indicated by longer tunnel lengths. The damage would probably have been as a result of more generations of the pest infesting the crop at this stage. Similar result has also been observed in Zambia by Moonga (2007) who reported that *C. partellus* damage was higher at the maturity stage of the crop.

3.5 Conclusion

C. partellus increased its share of species complex on both sorghum and wild host plants in all surveyed areas. However, it was abundantly recorded on cultivated sorghum over wild host plants. A variation in the number of the pest was also observed across locations with Bati and Dawa Chefa districts having the highest as compared to South Wollo district, Kalu. *C. partellus* density was at its peak during the seedling stage of sorghum and the lowest occurred at maturity stage. Similarly, infestation occured in all growing stages of sorghum crop in all the study areas in both seasons. However, it was found to be higher at the lower stages of the crop and decreases as the plant grows older to maturity. *C. partellus* damage was higher at the maturity stage of sorghum and was observed in the farmer field ranging from slight leaf injury to dead heart and stem tunnelling.

Chapter 4

Abundance and impacts of natural enemies on population reduction of *Chilo partellus* (Swinhoe) at different phenological stages of sorghum in North Eastern Ethiopia

4.1 Introduction

Natural enemies are important biological agents in the control of lepdoptrean stemborers in Africa. Several parasitoids and predators contribute to natural mortality of *C. partellus* in the field. The exotic larval and pupal parasitoids, *C. flavipes* and *X. stemmator,* respectively have been reported attacking *C. partellus* on maize and sorghum (Overholt *et al*., 1997; Chinwada & Overholt, 2001). These parasitic wasps were introduced into East Africa as a classical biocontrol programms of cereal stem borer mainly *C. partellus*. *C. flavipes* impact has been recently evaluated in Kenya after establishment, and a reduction of 53% *C. partellus* population has been realized in some areas (Zhou *et al*., 2001). The parasitoid locates borers by laying eggs into them while feeding inside the plant stems. When they hatch, the larvae feed internally in the pest and kill it and then exit to spin cocoons (Zhou *et al*., 2001). *X. stammatar* behaves similarly, but it attacks pupae of *C. partellus*.

C. *flavipes* has never been released in Ethiopia though the first recovery of this parasitoid was made by Emana Getu *et al*. (2001). The source of this parasitoid in Ethiopia is unknown, but the study suggested that it could be from Kenya and Somalia releases of Mombasa town and Shebele river bank from Somalia side, respectively (Emana Getu *et al*., 2001 & Emana Getu, 2002). The exotic pupal parasitoid of *C. partellus*, *X. stammatar*

has been recently imported and released in several countries of Africa including Ethiopia (Emana, personal communication). The release of this parasitoid in Ethiopia was made around Kombolcha of south Wollo zone, but nobody checked its establishment. Predators are useful components of integrated pest managment (IPM) (Bonhof, 2000). Ants (Hymenoptera: Formicidae) are the most important in maize fields (Chinwada & Overholt, 2001; Emana Getu *et al*., 2001 & Emana Getu, 2002). They attack all stages of stem borers, and are among the few predator species preying on larvae and pupae. In Ethiopia earwigs (Dermaptera) and ants were commonly seen preying on *B. fusca* (Emana Getu *et al*., 2001 & Emana Getu, 2002).

In previous studies, host plant species significantly affected *C. partellus* parasitism by *C. flavipes* (Setamou *et al*., 2005 & Asmare Dejen *et al*., 2013). However, the effects of host plant growth stages were not assessed so far. Likewise, abundances of these natural enemies are expected to vary with different host stages and locations. Therefore, this study was carried to ascertain the effect of these natural enemies in relation to the status of this pest in the focused areas. The objectives of this study were:

- to assess the abundance and distribution of natural enemies at the different growth stages of sorghum crops
- to assess the parasitism levels of *C. flavipes* at different growth stages of sorghum in all the study areas at the time of the surveys.

4.2 Material and Methods

4.2.1 Description of the study area

Survey was conducted twice during 2016/17 and 2017/18 cropping seasons to determine the abundance and distribution of natural enemies, and parasitism levels of *C. flavipes* at different growth stages of sorghum in the same locations (Figure 3.1), but on different sorghum fields.

4.2.2 Design and sampling procedure

During the surveys sorghum fields were examined for possible infestation of *C. partellus* and the presence of any natural enemies. A total of nine fields having similar sowing dates and the same variety (var. Degalit) were randomly sampled from each locality. Each farm was divided in to 5 quadrats (4m x 4m); where 4 laid in the corner and 1 in the middle. Survey was conducted at all growth stages of sorghum. At seedling stage 4 plants were randomly selected and tagged per quadrat to check for the presence or absence of borers and any natural enemies in a field. At vegetative, heading and maturity stages destructive sampling were done. For the destructive sampling, 4 plants in each quadrat (20 plants per field) were randomly cut at ground level and dissected to check for stem borers and/or parasitoids. During stem dissections number of larvae, parasitized larvae, cocoons and dead larvae were recorded from 20 randomly selected plants and were kept individually in clean glass vials (2.5cm x 5cm) according to their localities and taken to the laboratory for adult wasps emergence and parasitism rate determination. Predators were examined at each quadrat per field.

Rearing of stem borer for identification and *C. flavipes* abundance

All developmental stages of stemborers were brought to Kombolcha Plant Health Clinic and reared in clean plastic beakers containing the same (natural) diet (Graham & Conlong, 1988), covered with loosely woven cloth at the temperature of 25-30^{o}C and relative humidity of 60-70% (Plate 4.1). Fresh sorghum stems provided as a natural diet were changed every three days until larvae pupated or parasitoids emerged. Larvae were identified at species level. Eggs, cocoons and pupae were placed in separate empty jars and sealed with perforated lids. Parasitoids, collected from the field and emerged from different developmental stages of *C. partellus* were identified to species level using the method described in chapter 3.

Parasitism rate determination

Parasitism (larvae) was recorded from the host insect that were collected from different growth stages of sorghum and observed for parasite emergence. Perecent parasitism was determined as:

$$\text{Parasitism} = \frac{\text{Number of parasitized larvae}}{\text{Total number of larvae}} \times 100$$

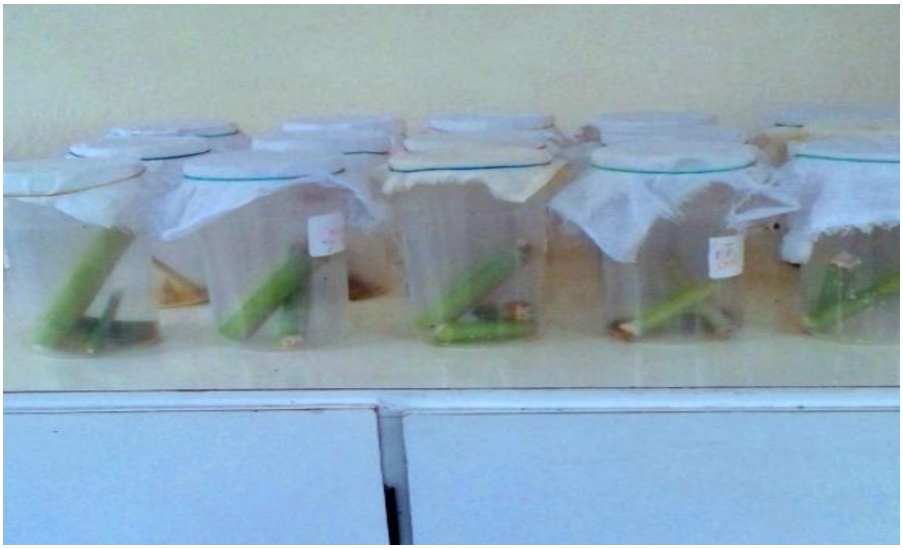

Plate 4.1 Rearing of stem borers in the laboratory for identification and *C. flavipes* abundance: Plastic beakers containing a 3-5cm section of natural diet (sorghum stems) as food source for the larvae

Data analysis

Data obtained from surveys and the laboratory were analysed using SPSS Version 16 software. Means were separated at 5% level using LSD. Insect counts were subjected to log (x+1) transformations before statistical analysis (Gomez and Gomez, 1984).

4. 3 Results

4.3.1 Parasitoid species compositions and their abundance on sorghum in 2016/17 & 2017/18

The major *C. partellus* parasitoids that were found on sorghum were from two orders, and four families (Table 4.1). Significant number of eggs and larval parasitoids were recorded from all the study areas. The larval parasitoid, *S. parasitica* recovered from *C. partellus* larvae that were collected from Bati. The pupal parasitoid, *Dentichasmias busseolae* Heinrich (Hymnoptera: Ichneumonidae) was recovered from all sites except Bati. The larval parasitoid of *C. partellus, C. flavipes* was dominant in all regions of Oromia.

Table 4.1 Parasitoid species composition and their abundance on sorghum plants (pooled data over years)

				Dominance (%)		
Parasitoids species	Order	Family	Host stage attacked	Kalu	Bati	Dawa Chefa
Cotesia flavipes	Hymnoptera	Braconidae	L	26.2	45.7	44
Cotesia sesamiae	Hymnoptera	Braconidae	L	30.0	19.8	21
Dentichasmias busseolae	Hymnoptera	Ichneumonidae	P	6.2	0	4
Sturmiopsis parasitica	Diptera	Tachinidae	L	0	4.3	0
Egg parasitoids	Hymnoptera	Trichogrammatidae	E	37.5	30.2	31

L =Larva, P=pupa, E =egg. The egg parasitoids were Trichgramma & Telenomus species

4.3.2 Abundance of *C. flavipes* at different growth stages of sorghum

C. flavipes was recorded from different growth stages of sorghum but at seedling stage in all districts. However, its abundance differed significantly among different growth stages and at the three locations. The highest (0.99±0.02) mean abundance of *C. flavipes* was

recorded at maturity stage of sorghum from Bati and the lowest (0.77±0.06) was recorded at heading stage from Kalu district. However, no parasitoid (*C. flavipes*) was recorded at the seedling stages of sorghum in all districts (Table 4.2).

Table 4.2 Mean (±SE) number of parasitoids on sorghum at different areas of Kalu, Bati and Dawa Chefa districts during 2016/17 & 2017/18 (pooled data over seasons)

Districts	Plant growth stages	*C. flavipes*	*C. sesamiae*	*D. busseolae*	*Egg parasitids*
Kalu	Seedling stage	0.71±0.0^{b}	0.71±0.0^{b}	0.71±0.0^{a}	0.80±0.04^{ab}
	Vegetative stage	0.71±0.0^{b}	0.71±0.0^{b}	0.71±0.0^{a}	0.86±0.08^{a}
	Heading stage	0.77±0.06^{ab}	0.77±0.09^{ab}	0.73±0.02^{a}	0.76±0.04^{ab}
	Maturity stage	0.85±0.02^{a}	0.89±0.04^{a}	0.74±0.03^{a}	0.71±0.0^{b}
	Levels of significant	NS	NS	NS	NS
	LSD at .05	0.09	0.13	0.05	0.13
Bati	Seedling stage	0.71±0.0^{d}	0.71±0.0^{b}	0.71±0.0^{b}	0.83±0.06^{a}
	Vegetative stage	0.78±0.07^{c}	0.71±0.0^{b}	0.71±0.0^{b}	0.85±0.06^{a}
	Heading stage	0.93±0.02^{ab}	0.78±0.07^{ab}	0.71±0.0^{b}	0.79±0.08^{a}
	Maturity stage	0.99±0.02^{a}	0.86±0.07^{a}	0.76±0.05^{a}	0. 71±0.0^{a}
	Levels of significant	**	NS	NS	NS
	LSD at .05	0.07	0.13	0.06	0.15
Dawa chefa	Seedling stage	0.71±0.0^{c}	0.71±0.0^{b}	0.71±0.0^{b}	0.78±0.07^{a}
	Vegetative stage	0.78 ±0.04^{bc}	0.71±0.0^{b}	0.71±0.0^{b}	0.83±0.06^{a}
	Heading stage	0.82±0.57^{b}	0.78±0.07^{ab}	0.71±0.0^{b}	0.81±0.09^{a}
	Maturity stage	0.96±0.03^{a}	0.85±0.03^{a}	0.76±0.04^{a}	0.71±0.0^{aa}
	Levels of significant	**	**	NS	NS
	LSD at .05	0.10	0.09	0.04	0.17

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). **= Significant, NS= Not significant. The egg parasitoids were Trichgramma & Telenomus species

At Bati the relative abundance of *C. flavipes* was the highest (27.2%) followed by Dawa Chefa district which were recorded at maturity stages of sorghum. The relative abundance of *C. flavipes* was the lowest (25%) at Kalu (Table 4.3)

Table 4.3 Parasitoids recovered, number per district and relative abundance (%)

Location	Parasitoids recovered	Total number per district	Relative abundance
Kalu	*C. flavipes*	3.04	25.0
	C. sesamiae	3.08	25.4
	D. busseolae	2.89	23.8
	Egg parasitoids	3.13	25.8
	Total	12.14	100
Bati	*C. flavipes*	3.41	27.2
	C. sesamiae	3.06	24.4
	S. parasitica	2.89	23.0
	Egg parasitoids	3.17	25.3
	Total	12.53	99.9
Dawa Chefa	*C. flavipes*	3.27	26.5
	C. sesamiae	3.05	24.7
	D. busseolae	2.89	23.4
	Egg parasitoids	3.13	25.4
	Total	12.34	100

The egg parasitoids were Trichgramma & Telenomus species

4.3.3. Number parasitzed larvae by *C. flavipes* across the locations at different growth stages of sorghum

The average number of parasitized larvae of *C. partellus* ranged from 0-5.3 across the locations with Bati having the highest (5.33) number (Figure 4.1). The lowest (0.67) was from Dawa Chefa at vegetative stage. Similarly, all districts were statistically significant ($F=1.22$; d.f.=2; $P=0.03$). There were significant differences in the mean number of parasitized larvae in the three plant growth stages ($F=52.42$; d.f.=2; $P<0.000$) (Figure 4.2).

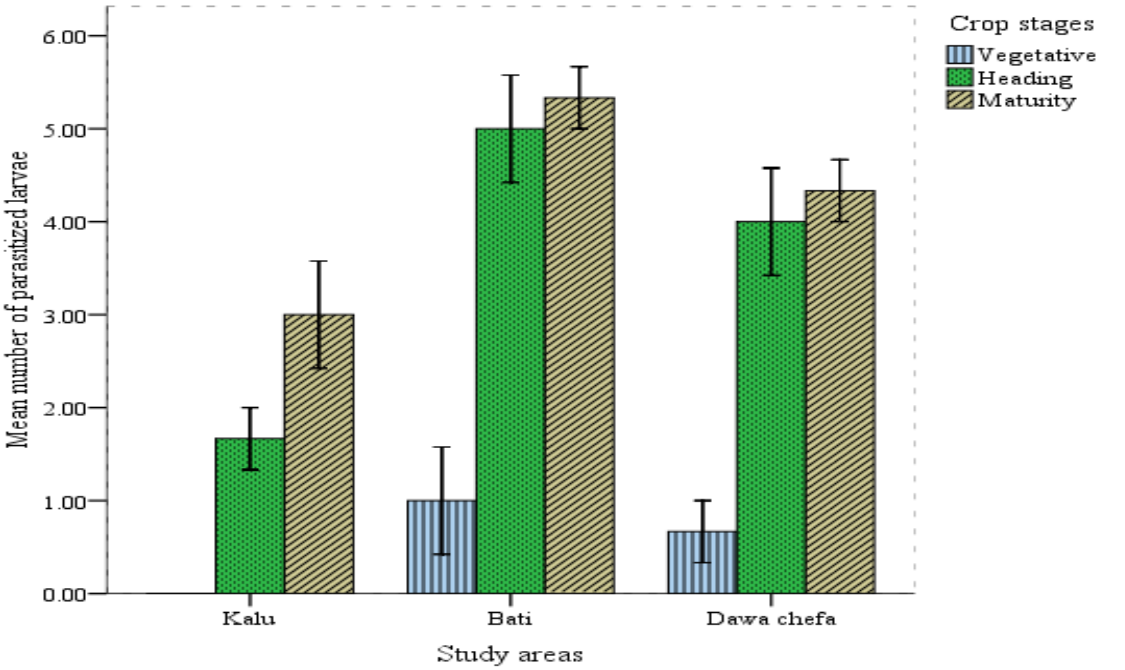

Figure 4.1 Mean numbers of parasitized larvae across the three locations

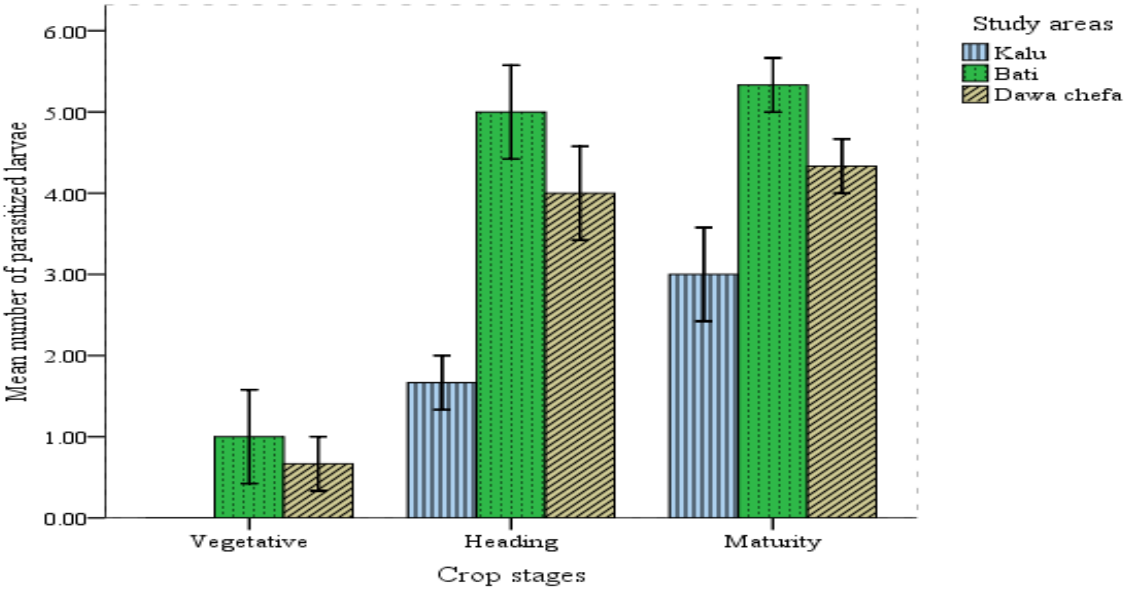

Figure 4.2 Mean numbers of parasitized larvae at three sorghum growth stages

4.3.4 Parasitism levels of *C. flavipes* across the locations at different growth stages of sorghum

Parasitism was recorded in all locations in the three growth stages except Kalu at vegetative stage. The highest percent parasitism (61.5%) was recorded from Bati at maturity stage. However, the lowest (11.7%) was from Dawa Chefa at vegetative stage (Table 4.4).

Table 4.4 Mean (±SE) percent parasitism of *C. partellus* by *C. flavipes* at different phenological stages of sorghum in Kalu, Bati and Dawa Chefa districts during 2016/17 & 2017/18.

Districts	Vegetative stage		Heading stage		Maturity stage	
	Parasitized larvae	% parasitism	Parasitized larvae	% parasitism	parasitized larvae	% parasitism
Kalu	0.00±0.00[c]	-	1.67±0.67[c]	16.7	3.00±0.57[c]	32.1
Bati	1.00±0.57[a]	14.2	5.00±1.15[a]	50.0	5.33±1.20[a]	61.5
Dawa chefa	0.67±0.32[b]	11.7	4.00±1.52[b]	36.4	4.33±0.87[b]	54.2

Means in the same column followed by the same letter are not significantly different at 5% level, (LSD).

4.3.5 Abundance of predator species as influenced by different growth stages of sorghum

Abundance of predators differed among different growth stages of sorghum and the three districts: Kalu, Bati and Dawa Chefa (Table 4.5). The highest (1.22±0.11) mean number of ants was recorded at vegetative stage from Dawa Chefa followed by Bati at maturity and the lowest (0.74±0.04) was recorded at seedling stage from Bati. Spider mean number was the highest (0.79±0.07) at vegetative stage that was recorded from Bati. The lowest (0.72±0.01) was found at seedling and maturity stages of sorghum from Dawa Chefa and Kalu districts, respectively. The mean number of earwigs was the highest

(1.13±0.06) at maturity stages. However, the number was not statistically different from that of Bati at this stage. The lowest (0.72±0.01) number of earwigs was recorded at heading stage from Kalu. Similarly, leadybird beetles abundance was the highest (0.87±0.15) at vegetative stage from Kalu. However, the number was not statistically different at the lower stages of sorghum in all districts (Table 4.5).

Table 4.5 Mean (±SE) predators abundance at different growth stages of sorghum during 2016/17 & 2017/18 (pooled data over seasons)

Districts	Plant growth stages	Ants	Spiders	Earwigs	Ladybird beetles
Kalu	Seedling stage	1.01 ±0.16^{a}	0.71±0.0^{a}	0.71±0.0^{a}	0.71±0.0^{a}
	Vegetative stage	1.13±0.05^{a}	0.74±0.03^{a}	0.71±0.0^{a}	0.87±0.15^{a}
	Heading stage	1.18±0.02^{a}	0.75±0.04^{a}	0.72±0.01^{a}	0.79±0.07^{a}
	Maturity stage	1.19±0.02^{a}	0.72±0.01^{a}	0.73±0.03^{a}	0.71±0.0^{a}
	Levels of significant	NS	NS	NS	NS
	LSD at .05	0.22	0.06	0.05	0.23
Bati	Seedling stage	0.74±0.04^{c}	0.71±0.0^{a}	0.71±0.0^{c}	0.71±0.0^{a}
	Vegetative stage	0.87±0.17^{c}	0.79±0.07^{a}	0.74±0.03^{bc}	0.72±0.0^{a}
	Heading stage	1.17±0.01^{ab}	0.73±0.02^{a}	0. 86±0.06^{b}	0.71±0.0^{a}
	Maturity stage	1.20±0.02^{a}	0.72±0.01^{a}	1.08±0.07^{a}	0.71±0.0^{a}
	Levels of significant	**	NS	**	NS
	LSD at .05	0.22	0.10	0.13	0.0
Dawa chefa	Seedling stage	0.71±0.0^{c}	0.72±0.01^{ab}	0.71±0.0^{c}	0.72±0.01^{a}
	Vegetative stage	1.22±0.11^{a}	0.75±0.03^{a}	0.74±0.03^{c}	0.73±0.02^{a}
	Heading stage	0.79±0.07^{c}	0.71±0.0^{b}	0.87±0.07^{b}	0.72±0.01^{a}
	Maturity stage	1.19±0.01^{ab}	0.71±0.0^{b}	1.13±0.06^{a}	0.71±0.0^{a}
	Levels of significant	**	NS	**	NS
	LSD at .05	0.17	0.04	0.13	0.04

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). **= Significant, NS= Not significant

The relative abundance of predators differed among the three districts: Kalu, Bati and Dawa Chefa (Table 4.6). Result showed that the highest (33.7%) relative abundance of ant population was found at Kalu followed by Bati. The loest was recorded from Dawa

Chefa with the relative abundance of (29.8%). Spider showed the highest (22.3%) relative abundance followed by Dawa Chefa and the lowest (21.8%) relative abundance was found from Kalu.

The relative abundance of earwigs was the highest (26.3%) that was recorded from Dawa Chefa and the lowest (21.4%) was recorded from Kalu district. The relative abundance of ladybird beetle populations (23.0%) was recorded the highest from Kalu and the lowest (21.6%) was found from Bati (Table 4.6).

Table 4.6 Relative abundance (%) of predators on cultivated plants

Location	Number predators recovered	Total number per district	Relative abundance
Kalu	Ants	4.51	33.7
	Spiders	2.92	21.8
	Earwigs	2.87	21.4
	Ladybird beetles	3.08	23.0
	Total	13.38	99.9
Bati	Ants	3.98	30.3
	Spiders	2.95	22.3
	Earwigs	3.39	25.8
	Ladybird beetles	2.85	21.6
	Total	13.17	100
Dawa chefa	Ants	3.91	29.8
	Spiders	2.89	22.0
	Earwigs	3.45	26.3
	Ladybird beetles	2.88	21.9
	Total	13.13	100

4.3.6 Relationship between crop stages, damage caused by *C. partellus* and parasitism

Number of exit holes and tunnel length were positively related with the plant growth stages in both years and in all locations. Leaf injury was negatively related with the plant growth stages for both location and both years and it was significant at 0.05 level. In all the study sites percent parasitism was positively related with the plant growth stages and was significant at 0.05 levels (Table 4.7).

Table 4.7 Correlation analysis of crop stages, leaf damage, number holes, tunnel length and percent parasitism

Locations		Plant stage	Tunnel length	% parasitism
Kalu	Plant stage	-	1.00 (P=0.007)	1.00 (P=0.015)
	Leaf damage	-0.93 (P=0.021)	-	-
	Number holes	0.99 (P=0.055)	-	-
Bati	Plant stage	-	0.92 (P=0.253)	0.95 (P=0.084)
	Leaf damage	-0.89 (P=0.015)	-	-
	Number holes	0.95 (P=0.043)	-	-
Dawa Chefa	Plant stage	-	0.95 (P=0.002)	0.99 (P=0.091)
	Leaf damage	-0.86 (P=0.033)	-	-
	Number holes	0.97 (P=0.117)	-	-

Correlation is significant at 0.01 and 0.05 levels

4.4 Discussion

Regardless of the existence of large number of parasitoids associated with *C. partellus* (Assefa Gebre-Amlak, 1985 & Emana Getu *et al*., 2001), only the major parasitoids were recorded in this study. We collected 5 parasitoids (from 2 orders and 4 families) attacking this pest from sorghum fields. A total of 96, 176 and 9 egg, larvae and pupae parasitoids were collected, respectively (Appendix 4.1). The major *C. partellus* parasitoids that were found on sorghum were *C. flavipes, C. sesamaie, D. busseolae, S. parasitica and* egg parasitoid species. In this study, *C. partellus* was mainly attacked by several parasitoids on sorghum that may reflect the high abundance of these species in this respective habitat. The probable assumption may be, higher herbivore host density in cultivated sorghum that resulted in greater attraction of parasitoids leading to high host attack and mortality. Similar result also reported in Kenya by Zhou *et al*. (2003) who stated that high parasitoid diversity was recorded in cultivated host plants.

This parasitoid diversity in sorghum might be due to the fact that the plant may have reduced allelochemicalls toxicity or metabolites and higher level of nutrients for the borers which were suitable for the development of the parasitoids (Mailefiya *et al*., 2009). This quality of the host plant could support higher stem borer survival and thus greater parasitoids richness in sorghum. The current study recorded high number of natural enemies on different stages of sorghum. This implies that sorghum hosted stem borers at different stages that were attacked by more than two parasitoid species. In this view, beside the indigenous and exotic larval parasitoids, the other larval parasitoid species *S. parasitica* (Curran) (Diptera: Tachinidae) has the potential to improve

biological control of *C. partellus* as recorded from Bati on this host. This niche overlap among the parasitoids may serve to improve biological control efficacy in managing this pest.

C. flavipes was recorded from all the study areas on sorghum. However, it was abundantly recorded from Bati and Dawa Chefa districts. This high abundance of the parasitiod in these areas may be because of the suitable host (*C. partellus* was abundantly found on sorghum crops). Consistent with this study, Emana Getu *et al*. (2001 & 2002), Assefa Yihunie *et al*. (2008) and Asmare Dejen *et al*. (2013) reported that C. *flavipes* was highly abundant and contributed to the reduction of *C. partellus* population in low land areas of eastern Ethiopia. In this study the highest abundance of this parasitoid, also indicated that the wasp is well established in these area where *C. partellus* was dominantly found. The result also showed that *C. flavipes* was also recorded from Kalu districts where their altitudes are higher than Bati and Dawa Chefa. The reason might be the distribution of *C. flavipes* was influenced by the geographical range of its respective host, *C. partellus* which could be one of the indicators of the host distribution to the high land areas. Therefore, considering the predicted expansion of *C. partellus* from warmer low to high altitude areas, *C. flavipes* is also expected to shift to these areas. Similarly abundance of *C. flavipes* was higher on the late growth stages than the early stages of sorghum. However, it was recorded as the most abundant species on maturity stage at all districts. This abundance at the late plant growth stage might be due to the necessity that mature larvae were the most important suitable host for the wasp.

The exotic, *C. flavipes* was introduced from Pakistan and India into Kenya (Overholt *et al*., 1994 & Zhou *et al*., 2001) from where it was released to other African countries (Overholt, 1998). The parasitoid has never been released in Ethiopia, but it is now found established on *C. partellus* in maize and sorghum (Emana Getu *et al*., 2001). The recovery of this parasitoid in these study areas indicates its establishment in the country that is crucial as a biocontrol agent in *C. partellus* management. Moreover, the other exotic pupal parasitoid *X. stammatar* has been imported and released in Ethiopia, particularly around Kombolcha of South Wollo zone (Emana, personal communication). This parasitoid appears to be an important part of integrated pest management plan to minimize the impact of the pest. However, in the present study the parasitoid was not recorded from the respective area. The reason for not to establish in the area is not known but probably the wasp had been mass reared on artificial diet in the laboratory and did not get any previous exposure on the target host, which might also have influenced their searching efficiency.

C. flavipes were recovered from *C. partellus* at the three plant growth stages in all locations except Kalu where no parasitized larvae or cocoons was recorded at vegetative stage. Although *C. flavipes*, has dramatically reduced population of this pest in all the study areas at each stage of sorghum, its rate of parasitism varied across the locations and growth stages. Parasitism by *C. flavipes* was higher at Bati and Dawa Chefa districts with the highest at Bati impling that the current status of this larval parasitoid is relatively better than at kalu. The other probable reason for the high rate of parasitism at Bati may be due to warmer and high temperature that could positively affect the performance of this parasitoid.

An interesting observation in this study was the pest and parasitism level pattern at the three plant growth stages. In all districts parasitism rate was observed the highest at maturity stage where pest population was lower. Parasitism levels were lower when pest populations were high at the lower growth stages. As the sorghum plant growth stage advanced, larvae populations became lower at maturity stage and parasitism increases. Similar result also reported in Ethiopia by Emana Getu (2002) who observed that parasitism of *C. partellus* by *C. flavipes* seemed to increase between the reproductive and maturity stages of the plant. Varkonyi *et al*. (2002) have also argued that low parasitism is likely to occur when the host is abundant and vice versa.

Parasitism of *C. flavipes* is affected by environmental factors such as temperature (Mendel *et al*., 1987), the host stage and quality (Tillman *et al*., 1993). During the study more parasitoid cocoons were recovered from parasitized mature larvae than the immature after dissection suggesting that the parasitoid laid significantly more eggs on larger hosts that may contain more resources for parasitoids growth. However, in gregarious species, parasitoids performance is not only affected by host size but also by the number of parasitoids developing in the host (Alleyne *et al*., 1997 & Jiang *et al*., 2004). Thus, mature larvae contain more *C. flavipes* immature and produce more cocoons than the immature larvae. A large number of *C. partellus* larvae parasitized by larvae and cocoons were collected in 2017/18 cropping season as compared to the previous season. Accordingly, the overall parasitism levels were higher (35.5%) in 2017/18 than observed in 2016/17 (32.9%) cropping season in the study areas. This might be due to a slow population increase of this parasitoid and its performance increases at maturity stages of the plant with time.

Predators' abundance differed significantly among different growth stages of sorghum crop in all districts. Ants were highly abundant at maturity and lower at early stages of the crop at Bati, while higher relative abundance was recorded at Kalu. This shows that among predators ants were dominant and most important in the district. Earwigs were highly abundant in Bati and Dawa Chefa districts while the maximum numbers was found from Dawa Chefa at maturity stage with higher relative abundance. In the present study, the highest number of ants and earwigs at late growth stages in these districts might be due to the sufficient number of prey at this stage. This result was not in agreement with Rahaman *et al.* (2014) who reported that the highest number of earwigs was recorded on the seedling stages of rice. Spiders and ladybird beetle found at the early growth stages. Spider abundance was higher at Bati and the maximum number was recorded on vegetative stage with low relative abundance.

The relative abundance of ladybird beetles was higher at Kalu though they were abundantly found in all study sites on the vegetative and heading stages of sorghum. The possible assumption for spider and lady beetles abundance at the vegetative stages of the crop might be eggs and neonate larvae that were available on fresh leaves of the crop at this stage. This result agreed with the finding of Rahman *et al.* (1991) and Mondal & Chakraborty (2017). They found that increasing number of ladybird beetles, *Micraspis discolor* was observed at the flowering stage of rice.

4.5 Conclusion

Five parasitoids from two orders and four familes were recorded during the study. The larval parasitoid of *C. partellus*, *C. flavipes* was abundantly recorded at the late growth stages of sorghum in all study sites with the highest at Bati. Parasitism of *C. flavipes* was higher during the study period. This parasitoid was observed as an important mortality factor of *C. partellus* larvae on the late growth stages of sorghum in both seasons. Evidences provided by field data in this study showed that the other exotic pupal parasitoid of *C. partellus, X. stammatar*, was generally absent during all seasons in the area of release. Among predators ants and earwigs were found the most abundant species attacking this pest at the late growth stages of sorghum at Kalu and Dawa Chefa districts, respectively. Thus it can be concluded that across the regions the importance of these natural enemies on different growth stages of sorghum appears to be increasing.

Chapter 5

Effect of some botanicals and cow urine against *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) under laboratory condition

5.1 Introduction

Application of chemical insecticides has been recommended to protect sorghum crop from *C. partellus* attack. However, chemicals are too expensive for subsistence farmers in most parts of Africa. They are also the cause of environmental and health hazards if not used judiciously or with proper safety measures (Williamson, 2003 & Vitale *et al*., 2007). Pesticides that have a sub-lethal toxicity to target pests, but still kill natural enemies of the pests may cause target pests to increase, resulting in even higher yield losses (Thippeswamy *et al*., 2010 & Kipkoech *et al*., 2010).

Therefore, effective and economically feasible *C. partellus* control practices need to be made accessible to farmers. Bio-pesticides from plants and animals are desirable alternatives to synthetic insecticides for controlling pests. They are cheap, readily available and affordable which can be an important option for poor farmers of developing countries including Ethiopia. Bio-pesticides are best suited for use in organic food production and play a great role especially in developing countries as a new class of eco-friendly products in controlling pests (Kareru *et al*., 2013 & Islam *et al*., 2013). In most cases their bioactive compounds are fairly complex groups, thereby making it more difficult for the pest to develop resistance (FAO, 2014; Khan *et al*., 2015 & Wahedi *et al*., 2016). Most botanicals are safe to prepare and apply, cheaper and selectively more

effective than synthetic insecticides. Moreover, they are considered to be environmentally friendly and also reduce the cost of insecticides in pest management (Vitale *et al*., 2007).

In many studies, a large number of local plant groups have been investigated and reported against a range of agricultural pests. However, there is insufficient study carried out, or documented report regarding plant and animal-based insecticides efficacy test for the control of *C. partellus*. Screening effective plant and animal-based insecticides is crucial in controlling *C. partellus.* Thus, this study was conducted:

- to determine the efficacy of specific plant and animals-based insecticides against *C. partellus* and finally to find out the best product to control this pest.

5.2 Material and Methods

5.2.1 Description of the study area

The study was conducted at Kombolcha Plant Health Clinic (KPHC), during 2016/17 under laboratory conditions (25-28^{0}C) and relative humidity (70±5 %). Kombolcha town is located in north-central Ethiopia, Debub Wollo Zone of the Amhara Region far away by 375 km from Addis Ababa. Geographically, it has a latitude and longitude of 11°6'N 39°43'E with an elevation of 1842 meters above sea level. The mean maximum and minimum temperatures are 26.3^{0}C and 13.2^{0}C, respectively.

Experimental materials

Collection and rearing of the insect

C. partellus eggs were collected from the field one to three weeks after plant emergence. After 5-11 days, the newly hatched larvae were reared on fresh sorghum leaves and mature larvae on fresh sorghum stems (Plate 4.1). The standard natural diet was prepared using fresh pesticide free sorghum leaves and stalks. They were allowed to feed on 4-week old sorghum leaves for 2-3 days before application of the treatments. Larvae were screened in the laboratory for confirmation of *C. partellus* using identification key.

Description of the test plants and animal product

The plant used for this study was *Millettia ferruginea* Hochst Baker commonly called as Birbira. The tree belongs to the family Fabaceae (Leguminosae). It is a useful endemic tree species of Ethiopia. Its natural habitat is rather diverse and common between 1000-2500m a.s.l. The two known subspecies of Millettia in Ethiopia are: *M. ferruginea ferruginea* confined to the northern parts of the country and *M. ferruginea drasana* which occurs in southern provinces, particularly Sidamo regions (Bekele Jembere, 2002). Trees from central to western Ethiopia shows mixture of these two species (Azene *et al*., 1993 as cited in Bekele Jembere *et al*., 2005). Both species can grow to rather big trees, attaining the size of up to 25m. The flowers are often violet and eventually bearing big flat pods (having the size of 27cm x 3cm). The pods usually contain 5 to 10 seeds and when dried, split open along both sides to release circular and flattened seeds.

M. ferruginea has been traditionally used for fish poisoning when mature pods and seeds are ground to fine powder and is spread over the water surface. The fish stunned by the effect of the drug start to come close to the surface, thus enabling an easy catch. However, there has not been any report of human death related to the consumption of birbira intoxicated fish (Siegenthaler, 1980). *M. ferruginea* is a multipurpose tree. It is highly decomposed, its green leaves contained high concentration of C, N and P and has a great potential as green manure for soil improvement (Gindaba *et al*., 2004). Its seeds and stem barks contained one of the dominant bioactive compounds 'rotenone' toxic against insect pests. The crude extract from seeds of *M. ferruginea* was found to be toxic to *Sitophillus zeamais* Motschulsky (Bekele Jembere, 2002) and to the maize stem borer *B. fusca* (Beniam Tilahun & Ferdu Azerefegne, 2013). In combination with other botanicals, it was found to be effective against *C. partellus* (Muzeyi & Bekele Jembere, 2005).

Phytolacca dodecandra L'Herit, commonly called as "Endod", belongs to the family Phytolaccaceae. It is a native herb to Ethiopia and grows as a weed in many parts of the country. *P. dodecandra* is perennial, climbing plant with hanging branches, growing up to 10m and usually fruits twice a year. Its small berries when dried, powdered and mixed with water produce a foaming detergent solution that has been traditionally used in Ethiopia for washing clothes. Furthermore, it has also insecticidal properties against awide range of insect pests. The insecticidal properties of this plant were reported by several authors. Assefa Gebre-Amlak and Ferdu Azerefegne (1999) noted that fruits extracts of *P. dodecandra* significantly reduced the levels of leaf infestation and dead heart injury due to larvae of *B. fusca*. Likewise, powdered *P. dodecandra* berry applied

on sorghum grain has resulted in high percent adult mortality, reduced progeny emergence, and low percent grain damage against the maize weevil, *S. zeamais* (Asmare Dejen & Eshetu Belete, 2001).

Cow urine is an organic animal product containing 95% water, 2.5% UREA and the remaining 2.5% a mixture of salts, hormones, enzymes and minerals (Bhadanuria, 2002). It has been considered that cow urine is very useful in agricultural operations as a bio-fertilizer and bio-pesticide as it kills a number of pesticide and herbicide resistant bacteria, virus and fungi (Dhama *et al*., 2005). According to the urine government department of animal husbandry, dairy and fisheries in India "Cattle urine is a powerful natural pesticide and if used properly can save human beings from the harmful effects of pesticide residue" (Reddy *et al*., 2016).

The insecticidal properties of cow urine were reported by several authors. The effect of plant products in combination with cow urine were reported from India in reducing sorghum shooty fly (*Arthericona soccata*) infestation. For example, Shrinivas and Balikai (2009) recorded least (0.47) number of eggs per plant and percent 21.0% dead hearts as compared to 67.6% untreated control when neem kernel seed extract + Cow urine (5%) sprayed on sorghum at 28 days after emergence. Similarly, the banana fly (*Drosophila melanogaster*) Meigen treated with 3 days fermented cow urine (1:6) resulted in 79.6% mortality as against 2.8% in control. Cow urine was also reported effective against cowpea aphid, *Aphis craccivora* Koch (Adane Tesfaye & Gautam, 2003).

Collection of botanicals and cow urine

Seeds of *M. ferruginea* and *P. dodecandra* used for the study were collected from their natural habitats. *M. ferruginea* seeds were collected from Addis Ababa University, Arat-kilo Campus. *P. dodecandra* seeds were obtained from road side grown voluntarily plantations at Dessie town, Ethiopia. Cow urine was collected from the local dairy farm of Dessie town in the morning into a plastic container.

Preparation of treatments

Birbira and Endod seed powders

M. ferruginea and *P. dodecandra* seeds were washed and dried in a well-ventilated area under shade for 15 days. After complete drying, seeds were ground into fine powder manually using home-made mortar and pestle (Bekele Jemberie, 2002; Beniam Tilahun & Ferdu Azerefegne, 2013). The powder was kept separately in packed plastic bag containers in a refrigerator at 4°c until when needed and used for its crude extractions.

Aqua extracts of botanicals and fermented cow urine

Powder of the botanicals that were kept in a sealed polythene bag in a refrigerator at 4°c was used for crude extractions. Each sample of 50gm powder weighed separately for crude extractions (Venkat *et al*., 2012). Each sample was mixed with 100ml solvent (water) in a separate flask. The mixtures were stirred for 15 minutes using a magnetic stirrer at room temperature until homogenous solutions formed and then left to stand for one day.

After 24 hrs, each mixture filtered through double folds of Muslin cloth to obtain the filtrate and allowed to evaporate the solvent. After evaporating the solvent, solid extracts left on each container and kept spread for a day in a ventilated room for further removal of the solvent. The solid extracts were used to prepare the serial dilutions. Each serial concentration was prepared by dissolving 100mg, 150mg and 200mg of fine powder with 100ml of distilled water (i.e to form 1.0ml, 1.5ml, and 2.0ml dilution or concentration) levels. The solutions were then thoroughly mixed until lemonade solution formed and ready for application on the 2^{nd} and/or 3^{rd} instar *C. partellus* larvae for bioassay. The collected cow urine was left for fermentation for 6 ± 1 days under shade at room temperature (Verena, 2007). After fermentation the content was sieved and became ready for spraying in similar manner with the extract concentration (Table 5.1). Before application, the urine was diluted with water at the ratio of 1:3 (v/v).

Treatment combinations

Treatment combinations (Cow urine + *M. ferruginea* and Cow urine + *P. dodecandra*) were prepared by mixing equal volumes of Cow urine with equal volume of each extract. Then each 100ml, 150ml and 200ml of the mixtures was added to 100ml of distilled water (v/v) to get 1.0ml, 1.5ml and 2.0ml concentrations. Water was used as a control and all treatments were compared with the untreated check (Table 5.1).

Table 5.1 List of treatments used in the management of *C. partellus* on sorghum

S.No.	Treatments	Local name	Parts used	Concentrations:		
				Day 1	Day 2	Day 3
1	*M. ferruginea* powder	Birbira	Seeds	1.0mg	1.5mg	2.0mg
2	*P.dodecandra* powder	Endode	Seeds	1.0mg	1.5mg	2.0mg
3	*M. ferruginea* aqua extract	-	Seeds	1.0ml	1.5ml	2.0ml
4	*P.dodecandra* aqua extract	-	Seeds	1.0ml	1.5ml	2.0ml
5	Fermented cow urine	Cow urine	-	1.0ml	1.5ml	2.0ml
6	*M. ferruginea* aqua extract + FCU	-	-	1.0ml	1.5ml	2.0ml
7	*P.dodecandra* aqua extract + FCU	-	-	1.0ml	1.5ml	2.0ml
8	Control (untreated check)	-	-	-	-	-

FCU - Fermented cow urine

5.2.2 Experimental design and treatment application

The experiment was laid out in a Completely Randomized Design (CRD) with three replications. In each replicate of Petri dish 10 larvae were added with a total of 240 larvae. The experiment was conducted at the same temperature and humidity of rearing condition. *M. ferruginea* and *P. dodecandra* seed powders were incorporated with the natural diet at 2.0g, 2.5g and 3.0g immediately after it was prepared per Petri dish. Similarly, aqua extracts (w/v) of the powders, and the mixtures (v/v) with the concentrations, 1.0ml, 1.5ml and 2.0ml were sprayed on the ten *C. partellus* 2^{nd} and/or 3^{rd} instars larvae per Petri dish, and preserved food was provided with pieces of sorghum stalk. The number of larvae was recorded before spray and every 24h after treatment applications till 3 days. Percent mortality over control was calculated using Abbott formula (Abbott, 1987).

$$P = \frac{Ta - Ca}{100 - Ca} \times 100$$

Where P = the corrected percent mortality;

Ta = the observed percent mortality in a treatment;
Ca = the percent mortality in the control

The best performing insecticide (s) of each concentration was selected for subsequent field experiments. The data obtained in laboratory test and field trial were used to determine the efficacy of the treatments.

Data analysis

Data were analysed using Proc GLM procedure of SAS (SAS, 9.0). Count data were subjected to analysis of variance (ANOVA). Significant means were separated using Least Significant Difference (LSD) at 0.05 levels.

5.3 Results

5.3.1 The effect of biopesticides on larval mortality of *C. partellus* after 1 day of treatment application

Effect of bio-pesticides on larvae of *C. partellus* showed that all rates significantly ($P<0.05$) differed (Table 5.2). After 1 day of treatment application, about 0.3-86.6% percent mortality was observed when compared to untreated control (0.33%). All treatments caused rate dependent mortality. The highest (86.6%) percent larval mortality was recorded on *M. ferruginea* aqua extract at the higher (2.0ml) rate and the lowest (0.33%) percent mortality was observed at the lower (2g and 1ml) rates of *P. dodecandra* powder, aqua extract and cow urine + *P. dodecandra*, respectively, However, mortality at these treatments was not stastically different from the control.

Table 5.2 Mean (±SE) percentage of cumulative mortality of *C. partellus* larvae at different application rates of bio-insecticides

Botanicals	1 day after treatment application		
	Rates (g) and ml/lt		
Powders	**2.0g**	**2.5g**	**3.0g**
M. ferruginea powder	33.3 ± 8.8^{Ca}	53.3 ± 3.3^{Ba}	73.3 ± 3.3^{Ab}
P. dodecandra powder	0.33 ± 0.3^{Ccd}	16.6 ± 3.3^{Bbcdf}	26.6 ± 3.3^{Be}
Aqua extracts and mixtures	**1.0ml**	**1.5ml**	**2.0ml**
M. ferruginea aqua extracts	26.6 ± 12.02^{Dab}	53.3 ± 8.8^{Ca}	86.6 ± 3.3^{Ba}
P.dodecandra aqua extracts	0.33 ± 0.3^{Ccd}	16.6 ± 6.6^{Abcdf}	20.0 ± 5.7^{Aef}
Cow urine	16.6 ± 6.6^{Dbc}	30.0 ± 5.7^{Cb}	50.0 ± 5.7^{Bcd}
Cow urine + *M. ferruginea*	13.3 ± 3.33^{Dbcd}	26.6 ± 0.32^{Bbc}	56.6 ± 8.8^{Ac}
Cow urine + *P.dodecandra*	0.33 ± 0.3^{Ccd}	20.0 ± 5.7^{Bbcd}	26.6 ± 8.8^{Ae}
Control (Untreated check)	0.33 ± 0.32^{Acd}	0.33 ± 0.32^{Af}	0.33 ± 0.32^{Ag}
SE±	4.26	4.26	4.26
CV (%)	7.83	7.83	7.83
LSD at 0.05	12.23	12.23	12.23

Means followed by upper letter across row and lower letter within column are not significantly different at 5% level, LSD.

5.3.2 The effect of biopesticides on larval mortality of *C. partellus* after 2 days of treatment application

Data on the mortality of the 2nd and 3rd instar larvae of *C. partellus* showed that all the treatments were highly significant (P<0.05) and superior over the control after 2 days of treatment application (Table 5.3). All botanical treatments showed significantly (p< higher mortality) at the 2nd days of exposure time compared to the control. The highest larval (100%) mortality was recorded on *M. ferruginea* powder and aqua extract at the highest (3g) rate. Mortality at this rate was not statistically different from 2.5g powder. The highest (100%) larval mortality recorded for *M. ferruginea* aqua extract was at 2.0ml. *P. dodecandra* aqua extracts caused significantly lower (20.3%) mortality at the lower (1.0ml) rate of application (Table 5.3).

Table 5.3 Mean (±SE) percentage cumulative mortality of *C. partellus* larvae at different application rates of bio-insecticides

Botanicals	2 days after treatment application		
	Rates (g) and ml/lt		
Powders	**2.0g**	**2.5g**	**3.0g**
M. ferruginea powder	70.0 ± 5.7^{Ca}	86.6 ± 3.3^{Aa}	100.0 ± 0.0^{Aa}
P. dodecandra powder	50.0 ± 5.7^{Cbc}	56.6 ± 8.8^{Bbc}	60.0 ± 11.5^{Abc}
Aqua extracts and mixtures	**1.0ml**	**1.5ml**	**2.0ml**
M. ferruginea aqua extracts	53.3 ± 8.8^{Db}	66.6 ± 3.3^{Cb}	100.0 ± 0.0^{Ba}
P.dodecandra aqua extracts	20.3 ± 5.4^{Ddef}	23.3 ± 3.3^{Def}	36.6 ± 12.0^{Cde}
Cow urine	33.3 ± 8.8^{Fd}	56.6 ± 3.3^{Ebc}	63.3 ± 8.8^{Db}
Cow urine + *M. ferruginea*	33.3 ± 6.6^{Dd}	50.0 ± 10.0^{Ccd}	63.3 ± 3.3^{Bb}
Cow urine + *P.dodecandra*	23.3 ± 0.3^{Bde}	26.6 ± 6.6^{Be}	43.3 ± 8.8^{Ad}
Control (Untreated check)	3.33 ± 0.8^{Ag}	3.33 ± 0.8^{Ag}	3.33 ± 0.8^{Af}
SE±	5.07	5.07	5.07
CV (%)	9.42	9.42	9.42
LSD at 0.05	13.72	13.72	13.72

Means followed by upper letter across row and lower letter within column are not significantly different at 5% level, LSD.

5.3.3 The effect of biopesticides on larval mortality of *C. partellus* after 3 days of treatment application

Significant lethal effects of all the treatments on *C. partellus* larvae were found 3 days after treatment compared with the control (Table 5.4). Mortality was increased as the rate of the extract applied increased in concentration. All botanical treatments showed significantly (p< higher mortality) at 3 days of exposure time compared to the control. The highest (100%) larval mortality was recorded on *M. ferruginea* powder and aqua extract at the highest rates. Mortality (90-93.6%) at the lower rates was not stastically different from the highest rates of applications. The other treatments showed the highest larval mortality at the higher rates of applications. The lowest (26.6%) mortality was recorded in aqua extracts of *P. dodecandra* at the rate of (1.0ml) (Table 5.4).

Table 5.4 Mean (±SE) percentage of cumulative mortality of *C. partellus* larvae at different application rates of bio-insecticides

Botanicals	3 days after treatment application		
	Rates (g) and ml/lt		
Powders	**2.0g**	**2.5g**	**3.0g**
M. ferruginea powder	83.3 ± 6.6^{Ba}	93.6 ± 3.1^{Aa}	100.0 ± 0.0^{Aa}
P. dodecandra powder	53.3 ± 3.3^{Dcd}	56.6 ± 8.8^{Ccd}	73.3 ± 5.7^{Bd}
Aqua extracts and mixtures	**1.0ml**	**1.5ml**	**2.0ml**
M. ferruginea aqua extracts	80.0 ± 5.7^{Bab}	90.0 ± 5.7^{Aab}	100.0 ± 0.0^{Aa}
P.dodecandra aqua extracts	26.6 ± 3.3^{Df}	46.6 ± 8.8^{Cde}	53.3 ± 3.3^{Bef}
Cow urine	53.3 ± 5.7^{Dcd}	56.6 ± 3.3^{Ccd}	86.6 ± 6.6^{Bbc}
Cow urine + *M. ferruginea*	60.0 ± 5.7^{Dc}	70.0 ± 5.7^{Cc}	93.3 ± 3.3^{Aab}
Cow urine + *P.dodecandra*	46.6 ± 12.0^{Dde}	43.3 ± 8.8^{Cef}	60.0 ± 11.5^{Be}
Control (Untreated check)	3.33 ± 0.8^{Eg}	3.33 ± 0.8^{Eg}	3.3 ± 0.8^{Eg}
SE±	5.48	5.48	5.48
CV (%)	14.51	14.51	14.51
LSD at 0.05	11.56	11.56	11.56

Means followed by upper letter across row and lower letter within column are not significantly different at 5% level, LSD.

5.4 Discussion

Result of the laboratory experiment indicated that all treatments significantly resulted in *C. partellus* larval mortality compared to the untreated check. These results are in agreement with previous work of Tadele Shiberu *et al*. (2013) who reported that botanical products like water extracts of Birbira, Endode, Neem and Pyrethrum gave good control of termite pests.

There were highly significant ($P<0.01$) difference among treatments in laboratory after exposure of 72 hours. Among all the treatments used *M. ferruginea* powder and aqua extract were found to be the most toxic and caused the highest (86.67-100%) mortality within 48 hours at the higher rate of applications. *M. ferruginea* seeds powder and aqua extract have been reported to have insecticidal properties. For example, *M. ferruginea* seed powder extracts resulted in a 96% mortality rate of maize weevils, *Sitophillus zeamais* 72 days after treatment application (Bekele Jembere, 2002). The toxicity of the plant can be attributed to rotenone which is one of the dominant compounds found in the seed of *M. ferruginea* and is a well-known botanical insecticide through contact and stomach poisoning (Bekele Jembere *et al*., 2005). Damte Tebkew & Mekasha Chichaybelu (2002) also tested the toxicity of Millettia seed against Adzuki bean beetle, *Callsobruchus chinunesis* and found that it gave complete protection of stored chickpea for six months in the laboratory.

Laboratory study on the toxicity of cow urine against *C. partellus* larvae caused high mortality (86.6%) as compared to the control. Similar result was reported in India by Adane Tesfay and Gautam (2003) who reported that cow urine caused 80% mortality of

Welo bush cricket (WBC), *Decticoides brevipennis* (Raggea) in 12 hrs after treatment and reached 90% after 24 hrs and was at par with neem leaf extract. They also reported 79.6% fruit fly, *Drosophila melanogaster* (Meigen) mortality as compared with 2.8% in control and it was at least 3 times more effective than neem. Effect of mixture (*M. ferruginea* aqua extract and fermented cow urine) was not significantly different from *M. ferruginea* powder and aqua extract (93.0%) at the higher rate of application, 2.0ml after 72 hrs. Powder and aqua extracted of *M. ferruginea* caused significant larval mortality followed by the mixture (*M. ferruginea* aqua extract and fermented cow urine) at the lower rates. The other treatments showed larval mortality at the higher rates of applications. This shows that from the different treatments used powder and aqua extracts of *M. ferruginea* found to be the most effective as compared to all other treatments.

High mortality due to *M. ferruginea* when compared to other plant products could be attributed to the presence of bioactive and other bitter compounds responsible for anti feeding activity that result into the starvation and death of insects. Comparison of this result with previous work has shown consistency to Bekele Jembere and Daniel Getachew (2006) where water extracts of *M. ferruginea* caused higher toxicity to all the castes of termites in which 93 to 100% mortality was recorded at all concentration levels. *M. ferruginea* powder and seed kernel aqua extracts have been reported to be effective against various species of insects and are considered safe for human health and environments (Bekele Jembere *et al*., 2005; Muzeyi & Bekele Jembere, 2005; Beniam Tilahun & Ferdu Azerefegne, 2013).

In contrast, *P. dodecandra* aqua extract and the mixture (*P. dodecandra* and fermented cow urine) were least active as compared with the other treatments. Significant lethal effects of the treatments on larvae of *C. partellus*, found three days after treatment applications compared with the control. The assumption for this may be that the active compounds present in these treatments were less in amount. However, larval mortality due to these treatments was observed increasing as the exposure time of the pest to the treatment increased. As exposure time proceeds, there was a progressive increase in the toxicity of these treatments to the test insect registering appreciable mortality of *C. partellus* larvae.

The present data clearly showed that *P. dodecandra* aqua extract and the mixture (*P. dodecandra* and cow urine) required three days to kill 53.3 and 60.0% of *C. partellus* at the higher rates of applications, respectively. This implies mortality increases due to these treatments at the higher rates of treatments applications. Hence the days to higher larval mortality took significantly longer periods and required higher rates of applications. The probable assumption might be due to the slow acting effect of the potent insecticides present in these treatments. Comparison of this result with previous work has shown consistency to Tadele Shiberu (2013) who reported that mortality of *B. fusca* increases at the concentrations of the treatments and exposure time of the insect increases.

Thus these treatments are less effective against *C. partellus* larvae compared to other treatments tested within three days, however they were considered as moderately effective treatments on *C. partellus* control. *C. partellus* is an internal feeder. The larvae grow and normally develop successfully inside the stem to be mature. Therefore,

botanical extracts and fermented cow urine as a traditional pest control completely increased the mortality rate of spotted stem borer, *C. partellus* when applied in the early stages of this pest.

5.5 Conclusion

The study concluded that many of the treatments tested appear to be quite useful as local source of insecticides. The efficacy of these treatments varied with different concentrations and time intervals. However, all the treatments tested showed significant insecticidal property against *C. partellus*. Out of the 7 treatments tested, *M. ferruginea* powder and aqua extracts were having acute toxicity against C. *partellus* larvae. *P. dodecandra* powder, cow urine and the mixture of *M. ferruginea* aqua extract with fermented cow urine were observed to have relatively high insecticidal activity. *P. dodecandra* aqua extract and its combination with cow urine were observed to have low insecticidal activity. Therefore, from the current study, powder and aqua extract of *M. ferruginea*, cow urine and combination of *M. ferruginea* aqua extract with cow urine are identified as good alternatives to chemical pesticides in controlling *C. partellus*. However, further study is needed on this regard to confirm the efficacy of these plant and animal-based insecticides and their practical effectiveness under natural conditions against *C. partellus* without any side effects on none target organisms and the environment.

Chapter 6

Field evaluation of the promising plant and animal-based insecticides on naturally infested sorghum crop with *Chilo partellus* Swinhoe (Lepidoptera: Crambidae)

6.1 Introduction

In Ethiopia, the exotic *C. partellus* is the most important pest of sorghum at lower altitiude and warm areas of the country. The insect infest sorghum throughout its growth stages in field. Early instar larvae feed on young leaves in the whorl, which cause "dead heart", while mature larvae bore into the stems. In sever cases of infestations, plant growth is retarded, flowering and grain production is drastically reduced resulting in significant yield loss. As is common with other agricultural pests, the primary management option for *C. partellus* is synthetic insecticide. However, the associated problems of insecticides, such as environmental contamination, pest resistance and effects on non-target organisms, have spurred the search for new strategies for managing the pest with minimal effects on natural enemies

Plant and animal based insecticides have been used traditionally by resource limited small-scale farmers in Africa to protect their crops from damage of insect pests. In Ethiopia, extracts of fruits of chinaberry {*Phytolacca dodecandra* L.) and pepper tree (*Schinus molle* L.) significantly reduced the levels of leaf infestation and dead heart injury due to larvae of the maize stemborer, *B. fusca* (Assefa Gebre-Amlak & Ferdu Azerfagan, 1999; Emana Getu & Tsedeke Abate, 1999). Seed extract of *Millettia ferruginea* (Hochst.) has been observed to be effective in controlling the field insect pest,

B. fusca (Beniam Tilahun & Ferdu Azerefegne, 2013). Neem seed powder at the rate of 0.65-1gm with frequencies of 3-4 times applications provided substantial damage reduction and yield increments of sorghum (Asmare Dejen, 2008). In addition, Buss and Park-Brown (2002) in their report recommend that future research on the bio-pesticide preparations and application rates are a prerequisite for sustainable agriculture.

The insecticidal property of cow urine was ascertained in the laboratory in India. In the field cow urine was found to be effective against barly aphid, *Duraphis noxia* Mondov and Wollo bush cricket, *Decticoides brevipennis* Raggea in Ethiopia with more than double increase in yield. In combination with plant products it could be effective in manging insect crop pests as that of chemical pesticide apart from being environmentaly safe and eco-friendly in nature (Adane Tesfaye & Gautam, 2003). The use of these insecticides for field crops is not new, as it has been widely used by small scale subsistence farmers since several years ago in different parts of Ethiopia. However, their rate and frequency of application is not well investigated under field condition. Hence, assessing the effects of different rates and frequency applications of plant and animal-based insecticides on *C. partellus* infestation and natural enemies are vital.

Thus, the objectives of the present study were:

- to determine the effect of rates and frequency of applications of the tested plant and animal-based insecticides on *C. partellus* infestations under field condition
- to determine their effects on the larval parasitoid, *C. flavipes* on sorghum under field conditions

6.2 Material and Methods

6.2.1 Study site

The present study was conducted during the main cropping season in 2017/2018 at Chorissa kebele of Kombolcha town, in a farmer's sorghum field (Figure 3.1). Kombolcha is located in north eastern Ethiopia in Amhara National Regional State, South Wollo zone at a distance of 375 km from Addis Ababa. Its astronomical location is at 11°5' N latitude and 39°44' E longitude with an elevation of 1842 meters above sea level. The site receives 1020mm mean annual rainfall but with much variation in distribution and amount. The topography is lowland type represents an arid and semi arid ecology.

6.2.2 Field layout and management

The study was carried out on the farmer field of 16 x 35m plot size. The farmer was given all the required inputs as well as the produce at harvest after the necessary data were taken. Following the first rain in June local sorghum variety (var. Gedalet) was planted immediately after the land preparation. About 2 seeds were planted per hole, but after germination they were subsequently thinned to one plant per hole. The field was divided into 5 equal blocks. Each block was divided into 9 plots where 5 treatments allotted at random. Each plot had size of 2.5 x 3.5m or 8.75m^2 with spacing of 30cm and 75cm between plants and rows, respectively. The natural infestation of this field (sorghum) was expected to be high, due to high occurrence of *C. partellus* in the area. A few volunteer plants from last year crop and other alternative hosts distributed over the whole field were left undisturbed to enhance *C. partellus* infestation. No fertilizer was

applied and all the cultural practices were accomplished as per the local recommendation except insecticide application.

Botanicals collection and preparations

Collections of botanicals and Cow urine were as described in Chapter 5. The treatments were 1g, 2g and 3g powder. The serial concentrations were prepared by mixing 50g, 100g and 150g powder in 1 liter of water and filtered through double muslin cloth (Venkat *et al*., 2012). The solution is then worked out to be at 5, 10 and 15% concentration (w/v). Likewise 50, 100 and 150ml cow urine were added in 1L of water to get similar concentration. Treatment combination was prepared by mixing with equal volumes in 1:1 (v/v) ratio. Liquid soap at 0.1% was added as emulsifier (Berger, 1995 & Thippeswamy *et al*., 2010) and all treatments were made ready for spray. All treatments were compared with untreated check. Cow urine was diluted with water at the ratio of 1:3 (v/v) to reduce risk of sorghum leaves burning.

Method of treatments application

The treatments were applied two and three times in three rates of applications i.e 1, 2 and 3g powder and 5, 10 and 15% concentrations (Table 6.1). The total treatments were thirteen including a check. Treatment applications were made starting from three weeks after crop emergence. Seed powder was mixed with equal amount of sawdust at the ratio of 1:1 (w/w) and was directly placed on the funnel of the plants manually as proposed by Habtie Tekie, (1999). The other treatments were sprayed to the whorl of sorghum leaves using a hand operated sprayer. Untreated plots were used as a control. All applications

were conducted in the late afternoon of the day to avoid wind disturbance and to moisten the powder.

Table 6.1 Treatment details for the management of *C. partellus*

Treatments	Rates	Application interval	Applications times
M. ferruginea seed powder	1gm	1g/plant in 7 days interval	2 & 3 times applied
	2gm	2g/plant in 7 days interval	2 & 3 times applied
	3gm	3g/plant in 7 days interval	2 & 3 times applied
M. ferruginea seed aqoeus extract	5%	Each per plot sprayed in 7 days interval	2 & 3 times
	10%		
	15%		
Fermented cow urine	5%	Each per plot sprayed in	2 & 3 times
	10%	7 days interval	
	15%		
Cow urine + *M. ferruginea* extract	5%	The mixture in the ratio 1:1 was	2 & 3 times
	10%	sprayed per plot in	
	15%	7 days interval	
Sorghum (Untreated check)	-	-	-

Data collection

Data were recorded both pre and post treatment application. Pre-treatment application data were recorded one day before the first treatment application. Post treatment data per plots were recorded after 2 and 3 times spraying. Number of leaf damage and dead hearts were recorded as observed over time. Plots were visually rated for *C. partellus* leaf damage using 0 to 6 rating scale: 0=no leaf damage 1=0-10%, 2=11-20%, 3=21-30%, 4=31-40%, 5=41-50%, and 6= >51% based on the method of Kalule *et al*., 1997; Moonga, 2007). A rating of 6 reflected highly damaged leaf, whereas a rating of 0 indicated zero damaged. Density, dead larvae, plant height, borer holes count and stem tunnelling were determined by randomly selecting two infested plants per plot before harvest (the entire stems were stripped off their cover leaves and were observed for the

occurrence holes). To check parasitoids sorghum plants were uprooted and dissected and the exposed larvae and cocoons were taken into the laboratory where they reared until parasitoids emergence. 2 plants from each plot were randomly collected at maturity, threshed, sun dried for one week and weighed to calculate the average weight of grains. Yield was recorded on Kg/treatment basis and percent grain yield advantage (PGYA) was calculated using the formula (Asmare Dejen, 2008) as follows:

$$GYA\% = \frac{\text{(Mean grain yield of the treated plots-mean grain yield of untreated)}}{\text{Mean grain yield of untreated plot}} \times 100$$

$$\text{Dead heart (\%)} = \frac{\text{number dead heart in a plot}}{\text{Total plants in a plot}} \times 100$$

$$\text{Length of tunneling (\%)} = \frac{\text{Length of tunneling (cm)}}{\text{Total length of stem (cm)}} \times 100$$

Data analysis

For both experiments, data were analyzed using the Proc GLM procedure of SAS (SAS, 9.0). Count data were subjected to Square-Root transformation $(X+0.5)^{1/2}$ as described by Gomez and Gomez (1984). The transformed data were subjected to analysis of variance (ANOVA). Significant means were separated by Fisher's Least Significance Difference (LSD) at 5% error level.

6.3. Results

6.3.1 Pre-treatment application infestation of *C. partellus* on sorghum

Infestations were high on all the plots and were non-significant before treatment. After obtaining of pre-treatment data, plants showing damage symptoms were removed from the plots and treatments were applied. Then post treatment data were collected.

6.3.2 The effect of different rate and frequency of *M. ferruginea* seed powder on dead heart and percent leaf damage

Result showed that there were a significant ($P<0.05$) differences among application rates and frequencies in sorghum leaf damage and dead hearts. The percent leaf damage and dead hearts were significantly lower in the treated plots than the untreated check (Table 6.2). Leaf damage and dead hearts were decreased as the application rates increased. The highest and the lowest damages were 21-30 % and 0-10 %, respectively at the rate of 1g and 3g, in that order. Similarly, the highest (0.81 ± 0.46) and the lowest (0.27 ± 0.27) dead hearts were recorded on sorghum treated with 1g and 2g, respectively. No dead hearts were recorded at the rate of 3g powder. Regarding application frequencies there were significant differences in the percent leaf damage (Table 6.2). The highest percent leaf damage was in the plot that recived three times applications and the lowest in the plot of two applications at the higher rates. However, no dead hearts recorded at these applications.

Table 6.2 Mean (±SE) number of dead heart and percent leaf damage due to different rate and frequency of *M. ferruginea* powder application

Treatments	Rate (g)	Leaf damage score	Leaf damage (%)	Dead hearts
M. ferruginea seed powder	1	3.02±0.5^{bc}	21-30	0.81±0.46(1.10)^{b}
	2	2.66±0.12^{efg}	11-20	0.27±0.27(0.85)^{bc}
	3	1.78±0.09^{p}	0-10	0.0±0.00(0.71)^{c}
Untreated check	-	3.62±0.11^{a}	21-30	1.94±0.27(1.87)^{a}
	MSE	0.03		0.14
	$LSD_{.05}$	0.28		0.55
	Frequency			
M. ferruginea seed powder	0	3.62±0.11^{a}	21-30	1.94±0.27(1.87)^{a}
	2	1.1±0.21^{e}	0-10	0.0±0.0(0.71)^{c}
	3	2.0±0.17^{bcd}	11-20	0.0±0.0(0.71)^{c}
	MSE	0.12		0.08
	$LSD_{.05}$	0.49		0.41

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

6.3.3 The effect of rate and frequency of *M. ferruginea* aqua extract, cow urine and the mixture treatments on dead heart and percent leaf damage

The percent leaf damage and dead hearts were significantly lower in the treated plots than the untreated check (Table 6.3). Percent leaf damage and dead hearts decreased as the application rate increases. The highest percent of leaf damages 21-30% were recorded on sorghum treated with cow urine at the lower and the higher rates. The lowest 0-10% was recorded on the mixture and *M. ferruginea* extract at the rate of 15%.

The highest (0.82±0.4) mean number of dead hearts was recorded on sorghum treated with cow urine at the lower rate. The lowest (0.18±0.1) was recorded on sorghum treated with *M. ferruginea* seed aqua extract at the lower rate. No dead hearts were recorded at

the higher rates of *M. ferruginea* seed aqua extract and the lower and higher rates of the mixture treatment (Table 6.3).

Table 6.3 Mean (±SE) dead hearts and percent leaf damage due to different rates of *M. ferruginea* aqua extract, the mixture treatment and cow urine applications

Treatments	Rate (%)	Damage score	Leaf damage (%)	Dead hearts
M. ferruginea extract	5	2.91 ± 0.09^{bcd}	11=20	$0.18\pm0.18\ (0.82)^{c}$
	10	2.72 ± 0.10^{def}	11-20	$0\pm0.0\ (0.71)^{c}$
	15	1.93 ± 0.22^{p}	0-10	$0\pm0.0\ (0.71)^{c}$
Cow urine	5	3.13 ± 0.05^{b}	21-30	$0.82\pm0.47\ (1.06)^{b}$
	10	2.97 ± 0.05^{bcd}	11-20	$0.53\pm0.26\ (0.99)^{bc}$
	15	3.02 ± 0.05^{bc}	21-30	$0.27\pm0.26\ (0.85)^{bc}$
M. ferruginea + Cow urine	5	2.96 ± 0.05^{bcd}	11-20	$0.0\pm0.0\ (0.71)^{c}$
	10	2.41 ± 0.06^{gh}	11-20	$0.27\pm0.26\ (0.85)^{bc}$
	15	1.85 ± 0.15^{p}	0-10	$0.0\pm0.0\ (0.71)^{c}$
Untreated control	-	3.62 ± 0.11^{a}	21-30	$1.94\pm0.27\ (1.87)^{a}$
	MSE	0.03		0.14
	$LSD_{.05}$	0.28		0.55

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

Effect of application frequencies on percent leaf damage and dead heart

Concerning application frequencies there were significant differences among time of applications with the highest 11-20% leaf damage on sorghum treated with cow urine at two applications and the lowest 0-10% in plot of the mixture at three applications. Dead heart was recorded on sorghum treated with cow urine at two applications and untreated control (Table 6.4).

Table 6.4 Mean (±SE) number of dead hearts and percent leaf damage due to applications frequency of *M. ferruginea* aqua extract, the mixture treatment and cow urine

Treatments	Frequencies of applications			
	Application times	Damage score	Leaf damage (%)	Dead heart
M. ferruginea aqua extract	2x	2.1±0.14^{bc}	11-20	0.0±0.0 (0.71)^{c}
	3x	1.5±0.20^{e}	0-10	0.0±0.0 (0.71)^{c}
Cow urine	2x	2.2±0.12^{b}	11-20	0.81±0.32 (1.22)^{b}
	3x	2.1±0.22^{bc}	11-20	0.0±0.0 (0.71)^{c}
M. ferruginea +Cow urine	2x	2.0±0.17^{bcd}	11-20	0.0±0.0 (0.71)^{c}
	3x	1.2±0.17^{e}	0-10	0.0±0.0 (0.71)^{c}
Untreated control	-	3.62±0.11^{a}	21-30	1.94±0.27 (1.54)^{a}
	MSE	0.12		0.08
	LSD	0.49		0.41

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

6.3.4 The effects of rate and frequency of *M. ferruginea* seed powder on larval density per plant & dead larvae

Significance differences were found among the rates of *M. ferruginea* seed powder treatments regarding larvae density. The highest (1.8±0.16) larval density was obtained in the plot treated with the lowest rate of 1g powder. The lowest (0.6±0.32) was recorded in the plot treated with the highest rate of 3g (Table 6.5). No larvae were recorded in plots of two and three applications.

The highest (2.5±1.44) dead larvae were recorded on the higher 3g rate of application. The lowest number (0.8±0.43) was found at the lower rate of 1g powder (Table 6.5). No significant differences were observed among the frequencies of applications in proportion of dead larvae. However, the mean dead larvae were higher (1.6±0.76) at two applications.

Table 6.5 Mean (±SE) number of larvae/plant and dead larvae due to different rate and frequency of *M. ferruginea* powder application

Treatments	Rate (g)	Live larvae/plant	Dead larvae
M. ferruginea seed powder	1	1.8±0.16 (1.52)^{bc}	0.8±0.43 (1.11)^{ef}
	2	1.7±0.87 (1.38)^{bc}	1.2±0.21 (1.30)^{b}
	3	0.6±0.32 (1.05)^{e}	2.5±1.44 (1.59)^{a}
Untreated check	-	3.3±0.43 (1.95)^{a}	0±0.0 (0.71)^{g}
	MSE	0.10	0.20
	$LSD_{.05}$	0.47	0.66
	Frequency		
M. ferruginea seed powder	0	3.3±0.43 (1.95)^{a}	0±0.0 (0.71)^{g}
	2	0±0.0 (0.71)^{e}	1.6±0.76 (1.40)^{ab}
	3	0±0.0 (0.71)^{e}	1.5±0.65 (1.37)^{abc}
	MSE	0.12	0.16
	$LSD_{.05}$	0.51	0.58

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

6.3.5 The effect of rate and frequency of *M. ferruginea* aqua extract, cow urine and the mixture treatments on larval density per plant & dead larvae

Significant differences were observed among rates and frequencies in proportion of mean larval density and dead larvae (Table 6.6). Higher rates had lower larvae density. The highest larval density (2.1±0.43) was obtained in the plot treated with cow urine at the lower rate (5% concentration) and this was not significantly different from all others at the lower rates. The lowest (0.8±0.43) was recorded on sorghum treated with *M. ferruginea* aqua extract at the higher rate of 15%.

The highest mortality (2.67±0.16) was recorded in the plot treated with the mixture at the higher rate of 15% concentration. The lowest (0.7±0.32) was recorded on sorghum treated with cow urine at the lower rate of 5% conc. (Table 6.6)

Table 6.6 Mean (±SE) number of larvae/plant and dead larvae due to different rates of *M. ferruginea* aqua extract, the mixture treatment and cow urine applications

Treatments	Rate (%)	Live larvae/plant	Dead larvae
M. ferruginea aqua extract	5	2.0±0.57 (1.55)^{b}	1.0±0.57 (1.17)^{ef}
	10	1.5±0.28 (1.40)^{c}	1.8±0.92 (1.43)^{bcd}
	15	0.8±0.43 (1.11)^{e}	2.3±0.72 (1.65)^{ab}
Cow urine	5	2.1±0.43 (1.62)^{b}	0.7±0.32 (1.05)^{f}
	10	1.8±0.16 (1.52)^{bc}	1.2±0.72 (1.22)^{ef}
	15	1.5±0.28 (1.40)^{c}	1.5±0.86 (1.33)^{cde}
M. ferruginea +Cow urine	5	2.0±0.0 (1.58)^{b}	1.3±0.87 (1.26)^{ef}
	10	1.5±0.28 (1.33)^{c}	2.1±1.09 (1.52)^{abc}
	15	1.3±0.87 (1.26)^{cd}	2.6±0.16 (1.77)^{a}
Untreated control	-	3.3±0.43 (1.95)^{a}	0±0.0 (0.71)^{g}
	MSE	0.10	0.20
	$LSD_{.05}$	0.47	0.66

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

Effect of application frequencies on number of larvae/plant & dead larvae

Higher number of larvae per plant were recorded at both applications in plots treated with cow urine. The lowest mean numbers of live larvae (0.3±0.40) were recorded in the plot treated with the mixture at the higher rate. No larvae were recorded in plots treated with *M. ferruginea* aqua extract at the higher rate (Table 6.7).

There is no signicant difference in mean number of dead larvae in each of the treatment frequencies of applications (Table 6.7). However, the highest (1.8±0.60) dead larvae were found in the plot of the mixture with three applications at the higher rate.

Table 6.7 Mean (±SE) number of larvae/plant and dead larvae due to applications frequency of *M. ferruginea* aqua extract, the mixture treatment and cow urine

Treatments	Frequencies of applications		
	Application times	Live larvae/plant	Dead larvae
M. ferruginea aqua extract	2x	0.6±0.53 (0.98)^{cd}	1.5±0.65 (1.34)^{abc}
	3x	0±0.0 (0.71)^{e}	1.7±0.76 (1.46)^{ab}
Cow urine	2x	1.2±0.69 (1.23)^{b}	1.0±0.40 (1.18)^{cde}
	3x	1.2±0.80 (1.32)^{b}	1.1±0.53 (1.22)^{bcd}
M. ferruginea +Cow urine	2x	0.7±0.56 (1.07)^{bc}	1.7±0.75 (1.44)^{ab}
	3x	0.3±0.40 (0.88)^{cde}	1.8±0.60 (1.56)^{a}
Untreated control	-	3.3±0.43 (1.95)^{a}	0±0.0 (0.71)^{g}
	MSE	0.12	0.16
	LSD	0.51	0.58

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

6.3.6 Correlations among treatments rates, frequencies, larval density and mortality

Applications rates and frequencies of the treatments were positively related to larval mortality and they were not significant. Applications rates of the treatments were negatively related to the density of laevae per plant. *M. ferruginea* aqua extract and *M. ferruginea* + Cow urine applications of frequencies were negatively related to the density of larvae while *M. ferruginea* seed powder and cow urine have no relations to the density of larvae and they were significant at 0.01 level (Table 6.8).

Table 6.8 The relationship between rates and frequencies of different treatments and larval mortality (%)

Treatments		Larvae per plant	Rates	Frequency
M. ferruginea seed powder	Dead larvae	-	0.240 (0.534)	0.447 (0.063)
	Rate	-0.520 (P=0.151)	-	-
	Frequency	0.000 (1.00)	-	-
M. ferruginea aqua extract	Dead larvae	-	0.363 (0.335)	0.233 (0.176)
	Rate	-0.529 (0.143)	-	-
	Frequency	-0.333 (0.176)	-	-
Cow urine	Dead larvae	-	0.333 (0.382)	0.132 (0.600)
	Rate	-0.548 (0.127)	-	-
	Frequency	0.000 (1.00)	-	-
M. ferruginea + Cow urine	Dead larvae	-	0.414 (0.268)	0.218 (0.384)
	Rate	-0.087 (0.824)	-	-
	Frequency	-0.243 (0.332)	-	-

Correlation is significant at 0.01 and 0.05 levels

6.3.7 The effects of rate and frequency of *M. ferruginea* seed powder on plant height, exit holes & tunnel length

There were significant differences (P<0.05) among the different rates and frequencies. The tallest plants (251.3cm) were recorded in the plots treated with 3g seed powder. While plot treated with 1g resulted in shorter (247.3cm) plants. As compared to the untreated check, the treated plots had significantly taller plants (Table 6.9). Plant height increases (253.3cm) at the two higher rates of applications of *M. ferruginea* seed powder.

Significant differences were recorded on number of exit holes among different *M. ferruginea* seed powder rate and frequencies. Large mean number of exit holes (2.85±0.05) per plant was recorded in the plots treated with the lower rate of 1g powder and the number (2.15±0.13) declined at the higher rate of 3g. There were significant differences among frequencies of applications. The largest exit holes (2.53±0.09) were

recorded in the plot recived three times application of the lower rates and the lowest (2.4±0.05) was at the higher rates of two applications. On the other hand, significantly more number of holes per plant (3.13±0.04) was recorded in untreated plots than the treated plots (Table 6.9)

A significance difference was observed on the mean larval tunnel length among different rates and frequencies of *M. ferruginea* seed powder applications. The longest tunnel length (19.0cm) was recorded on sorghum treated with lower rate of 2g powder, while the shortest (17.6cm) was at the higher rate of 3g powder. There were significant differences among frequencies of applications. The shortest (15.3cm) tunnel length was recorded at the higher rate of two times applications. The longest (16.6cm) was at the lower rate of three applications (Table 6.9).

Table 6.9 Mean (±SE) plant height, exit holes and tunnel length due to different rate and frequency of *M. ferruginea* powder application

Treatments	Rate (g)	Plant height (cm)	No. exit holes/plant	Tunnel length (cm)
M. ferruginea seed powder	1	247.3 ± 1.45^{bf}	2.85 ± 0.05^{bc}	18.6 ± 1.20^{cf}
	2	249.0 ± 0.57^{bc}	2.79 ± 0.05^{bcd}	19.0 ± 1.15^{bce}
	3	251.3 ± 2.02^{b}	2.15 ± 0.13^{ho}	17.6 ± 0.87^{fg}
Untreated check	-	213.0 ± 5.76^{c}	3.13 ± 0.04^{a}	23.7 ± 0.87^{a}
	MSE	29.08	0.03	4.15
	$LSD_{.05}$	7.87	0.26	2.97
	Frequency			
M. ferruginea seed powder	0	213.0 ± 5.76^{c}	3.13 ± 0.04^{a}	23.7 ± 0.87^{a}
	2	253.3 ± 0.76^{bc}	2.40 ± 0.05^{bd}	15.3 ± 0.28^{ef}
	3	252.6 ± 1.25^{bc}	2.53 ± 0.09^{bc}	16.6 ± 0.76^{def}
	MSE	2.34	0.78	1.43
	$LSD_{.05}$	2.23	1.28	1.75

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD).

6.3.8 The effect of rate and frequency of *M. ferruginea* aqua extract, cow urine and the mixture treatments on plant height, exit holes & tunnel length

There were significant differences ($P<0.05$) among different rates of applications in all treatments (Table 6.10). The tallest plants (253.6cm) were recorded in plots treated with *M. ferruginea* seed aqua extract at the higher rate of 15% concentration. While plots treated with cow urine resulted in shorter plants (247.0cm). As compared to the untreated check, the treated plots had significantly taller plants.

Large number of exit holes (2.90±0.0) per plant was recorded in the plot treated with cow urine at the lower rate of 5% conc. and this was not statistically different from the control. However, the number declined at higher rate of the mixture treatment. On the other hand, significantly more number of holes per plant (3.13±0.04) was recorded in untreated plots than the treated plots.

The longest (22.0cm) mean tunnel length was recorded on sorghum treated with cow urine at the lower rate of 5% conc., while the shortest (16.6cm) were on sorghum treated with the mixture at the rate of 15% conc. (Table 6.10).

Table 6.10 Mean (±SE) plant height, exit holes and tunnel length due to different rates of *M. ferruginea* aqua extract, the mixture treatment and cow urine applications

Treatments	Rate (%)	Plant height	Exit holes	Tunnel length
M. ferruginea aqua extract	5	252.3 ± 0.32^{ab}	2.53 ± 0.10^{efg}	19.0 ± 1.00^{bce}
	10	250.0 ± 0.57^{b}	2.46 ± 0.17^{efgh}	18.6 ± 0.87^{cf}
	15	253.6 ± 1.20^{a}	2.40 ± 0.13^{efgho}	17.0 ± 1.52^{fg}
Cow urine	5	249.3 ± 0.87^{bc}	2.90 ± 0.09^{ab}	22.0 ± 0.57^{ab}
	10	247.0 ± 1.15^{bc}	2.60 ± 0.05^{cde}	21.3 ± 0.87^{abc}
	15	251.0 ± 0.57^{b}	2.53 ± 0.10^{efg}	19.3 ± 0.66^{bc}
M. ferruginea +Cow urine	5	251.3 ± 0.66^{b}	2.47 ± 0.06^{efgh}	18.0 ± 1.15^{fg}
	10	252.0 ± 0.57^{ab}	2.59 ± 0.16^{def}	17.3 ± 1.52^{fg}
	15	253.0 ± 0.57^{ab}	2.33 ± 0.12^{gho}	16.6 ± 1.76^{fgh}
Untreated control	-	213.0 ± 5.76^{c}	3.13 ± 0.04^{a}	23.7 ± 0.87^{a}
	MSE	29.08	0.03	4.15
	$LSD_{.05}$	7.87	0.26	2.97

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD).

Effect of application frequencies on plant height, exit holes & tunnel length

Plant height increases as the application rate increases. Similarly, tallest plants (255.6cm) were recorded on sorghum treated with the mixture at the higher rate with three applications. The highest numbers of exit holes were recorded in the plot treated with cow urine at the lower rate of three applications. The lowest number of exit holes (2.25±0.1) were recorded in the plot treated *M. ferruginea* aqua extract with two applications at the higher rate (Table 6.11).

The longest tunnel length (21.0cm) was recorded on sorghum treated with cow urine at the lower rates with two applications. While the shortest (15.6cm) tunnel length was recorded on sorghum treated with *M. ferruginea* aqua extract at the higher rates with two applications (Table 6.11).

Table 6.11 Mean (±SE) plant height, exit holes and tunnel length due to application frequency of *M. ferruginea* aqua extract, the mixture treatment and cow urine at each rate

Treatments	Frequencies of applications			
	Application times	Plant height	Exit holes	Tunnel length
M. ferruginea aqua extract	2x	254.0±1.00^{ab}	2.25±0.16^{bdf}	15.6±1.04^{def}
	3x	254.6±0.76^{ab}	2.33±0.10^{bde}	17.0±1.00^{de}
Cow urine	2x	251.3±1.04^{bcd}	2.53±0.09^{bc}	21.0±0.57^{b}
	3x	253.0±0.49^{bc}	2.60±0.05^{ab}	19.0±1.00^{c}
M. ferruginea +Cow urine	2x	254.3±0.76^{ab}	2.33±0.10^{bde}	16.0±1.00^{def}
	3x	255.6±0.76^{a}	2.40±0.05^{bd}	17.3±0.76^{cd}
Untreated control	-	213.0±5.76^{c}	3.13±0.04^{a}	23.7±0.87^{a}
	MSE	2.34	0.78	1.43
	LSD	2.23	1.28	1.75

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD).

6.3.9 The effects of rate and frequency of *M. ferruginea* seed powder on the natural enemies of *C. partellus*

Plate 6.1 Cocoon mass of *C. flavipes* on larvae of *C. partellus*

Cocoon mass of *C. flavipes* was recorded from late growth stages (4th and 5th instar) of *C. partellus* larvae (Plate 6.1). Adult parasitoid, *C. flavipes* were recorded after rearing larvae of *C. partellus.* There were no significant differences among rates and frequencies in the cocoons number and moth emergence. However, larger cocoon numbers per plant (1.0±0.57) were collected from the plot treated with the lower rate of (2g) *M. ferruginea*

seed powder and this was not significantly different from the untreated control (Table 6.12).

Significant (0.6±0.49) numbers of cocoon mass per plant were collected from the plot treated with the lower rates of *M. ferruginea* seed powder at two applications. Similarly high numbers of adult *C. flavipes* were emerged from cocoons at the lower rates and two applications (Table 6.12).

Table 6.12 Mean (±SE) number cocoons (mass) and adult *C. flavipes* due to different rate and frequency of *M. ferruginea* powder application

Treatments	Rate (g)	Number cocoons (mass)	Number *C.flavipes*
M. ferruginea seed powder	1	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
	2	1.0±0.57 (1.22)^{c}	7.3±0.87 (2.78)^{ab}
	3	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
Untreated check	-	1.7±0.32 (1.46)^{c}	7.6±1.15 (2.83)^{a}
	MSE	0.03	0.44
	$LSD_{.05}$	0.28	0.96
	Frequency		
M. ferruginea seed powder	0	1.7±0.32 (1.46)^{a}	7.6±1.15 (2.83)^{a}
	2	0.6±0.49 (1.01)^{bc}	4.9±3.58 (1.89)^{bc}
	3	0±0.0 (0.71)^{e}	0±0.0 (0.71)f
	MSE	0.05	0.75
	$LSD_{.05}$	0.32	1.26

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

6.3.10 The effect of rate and frequency of *M. ferruginea* aqua extract, cow urine and the mixture treatments on the natural enemies of *C. partellus*

There was no significant difference among the different rates of applications in the cocoons number and moth emergence. However, larger cocoon number/plant (1.3±0.87) was collected from the plot treated with *M. ferruginea* aqua extract at the lower rate of 5% followed by cow urine (Table 6.13). the highest number of adult *C. flavipes* were

emerged from the cow urine treatments and the numbers were no statistically different from the untreated check.

Table 6.13 Mean (±SE) number cocoons and adult *C. flavipes* due to different rates of *M. ferruginea* aqua extract, the mixture treatment and cow urine applications

Treatments	Rate (%)	Number cocoons	Number *C. flavipes*
M. ferruginea aqua extract	5	1.3±0.87 (1.29)^{b}	7.0±3.51 (2.44)^{abc}
	10	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
	15	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
Cow urine	5	1.0±0.57 (1.17) ^{c}	7.3±3.84 (2.48)^{ab}
	10	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
	15	0.7±0.32 (1.05)^{d}	5.3±2.72 (2.17)^{d}
M. ferruginea +Cow urine	5	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
	10	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
	15	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
Untreated control	-	1.7±0.32 (1.46)^{a}	7.6±1.15 (2.83)^{a}
	MSE	0.03	0.44
	$LSD_{.05}$	0.28	0.96

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

Effect of application frequencies on cocoon number (mass) and adult *C. flavipes* emergence

Significant difference was observed in different applications frequencies in the number of cocoons and *C. flavipes* emergence (Table 6.14). However, larger cocoon numbers per plant (0.7±0.47) were collected from the plot treated with cow urine at the lower rate of 5% two applications, but the number were not stastically different with that of *M. ferruginea* aqua extract at this application. Likewise high numbers of adult *C. flavipes* emerged from cocoons at the lower rates of two applications of cow urine and *M. ferruginea* aqua extract and they were significantly different from the untreated control

Table 6.14 Mean (±SE) number cocoons and adult *C. flavipes* due to applications frequency of *M. ferruginea* aqua extract, the mixture treatment and cow urine

Treatments	Frequencies of applications		
	Application times	Number cocoons	Number *C. flavipes*
M. ferruginea aqua extract	2x	0.5±0.50 (0.96)^{bcd}	4.1±3.84 (1.65)^{cd}
	3x	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
Cow urine	2x	0.7±0.47 (1.05)^{b}	5.4±3.39 (2.06)^{b}
	3x	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
M. ferruginea +Cow urine	2x	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
	3x	0±0.0 (0.71)^{e}	0±0.0 (0.71)^{f}
Untreated control	-	1.7±0.32 (1.46)^{a}	7.6±1.15 (2.83)^{a}
	MSE	0.05	0.75
	LSD	0.32	1.26

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD). *numbers in parentheses are transformed $(X+0.5)^{1/2}$ value

6.3.11 The effects of rate and frequency of *M. ferruginea* seed powder on grain yield and yield advantage

No significant differences were recorded on grain yield among the different *M. ferruginea* seed powder rates and frequencies. The highest yield was recorded in the plot with the higher rate of 3g powder, while the lowest was recorded in the plot of the lower rate of 1g application. The yield advantage was also increased from 53.7% to 91.7%. There were no significant differences between two and three times application frequencies. However the yield advantage increased 92.5% in the plot recived two times application frequencies (Table 6.15).

Table 6.15 Mean (±SE) yield (kg/t) and yield advantage (%) due to different rate and frequency of *M. ferruginea* powder application

Treatments	Rate (g)	Yield kg/t	Yield advantage (%)
M. ferruginea seed powder	1	1.86±0.19abc	53.7
	2	1.97±0.28ab	62.8
	3	2.32±0.25a	91.7
Untreated check	-	1.21±0.13d	-
	MSE	0.11	
	$LSD_{.05}$	0.49	
	Frequency		
M. ferruginea seed powder	0	$1.21±0.13^{d}$	-
	2	$2.33±0.24^{a}$	92.5
	3	$2.32±0.24^{a}$	91.7
	MSE	0.14	
	$LSD_{.05}$	0.55	

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD).

6.3.12 The effect of rate and frequency of *M. ferruginea* aqua extract, Cow urine and the mixture treatments on grain yield and yield advantage

Grain yields vary among the different treatment rates that were ranging from 1.76kg/t to 2.30kg/t (Table 6.16). The highest yield was recorded in the plot of the mixture at the higher rate of (15%), while the lowest was in the plot of cow urine at the lower rate of (5%). In treated plots the entire rates gave high grain yield advantage as the rate increases. The highest percent yield advantage 90.0% was found in the plot that recived the mixture treatment at the higher rate, while the lowest (45.5%) was in plot treated with cow urine at the lower rate of 5%.

Table 6.16 Mean (±SE) yield (kg/t) and yield advantage (%) due to different rates of *M. ferruginea* aqua extract, the mixture treatment and cow urine applications

Treatments	Rate (%)	Yield kg/t	Yield advantage (%)
M. ferruginea aqua extract	5	1.82 ± 0.21^{abcde}	50.4
	10	1.94 ± 0.27^{abcd}	60.3
	15	2.28 ± 0.2^{ab}	88.4
Cow urine	5	1.76 ± 0.15^{cdef}	45.5
	10	1.98 ± 0.15^{abcd}	63.6
	15	1.94 ± 0.24^{abcd}	60.3
M. ferruginea +Cow urine	5	1.85 ± 0.18^{abcde}	52.8
	10	1.95 ± 0.12^{abcd}	61.1
	15	2.30 ± 0.15^{a}	90.0
Untreated control	-	1.21 ± 0.13^{g}	-
	MSE	0.14	
	LSD	0.55	

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD).

Effect of application frequencies on grain yield & yield advantage

Data on the frequencies of application on grain yield & yield advantage showed that the mixture treatment (2.33kg/t) and *M. ferruginea* aqua extract (2.31kg/t) were the best at three times applications than the others. The highest percent yield advantage 92.5% was recorded on the mixture treatment at the higher rate with three times applications, while the lowest was found on plots treated with cow urine at the lower rate of three times application (Table 6.17).

Table 6.17 Mean (±SE) yield (kg/t) and yield advantage (%) due to applications frequency of *M. ferruginea* aqua extract, the mixture treatment and cow urine

Treatments	Frequencies of applications		
	Application times	Yield kg/t	Yield advantage (%)
M. ferruginea aqua extract	2x	2.29±0.21abc	89.2
	3x	2.31±0.20ab	90.9
Cow urine	2x	2.0±0.24acd	65.3
	3x	1.96±0.30acd	61.9
M. ferruginea +Cow urine	2x	2.32±0.06ab	91.7
	3x	2.33±0.02a	92.5
Untreated control	-	1.21±0.13f	-
	MSE	0.14	
	LSD	0.55	

Means in a column followed by the same letter are not significantly different at 5% significance level, (LSD).

6.4 Discussion

Field result indicated that *C. partellus* infestations were significantly low with higher rate and frequency. *M. ferruginea* seed powder was found to be highly effective in reducing percent leaf damage and dead hearts at the higher rates with two applications followed by the mixture treatment with three applications. The reduced leaf damage and dead hearts may be related to the deterrence, antifeedant, inhibition of hormone and enzyme activity of the local insecticides. Consistence with this study, aqueous extract of neem seed kernel (*Aadrichata indica* A. Juss), nutmeg (*Monodora myristica* Gaertn.), Dunal and physic nut (*Jatroph curcas* L.), and castor oil (*Ricinus communis* L.) treated plots reduced percent dead heart and white heads than the un-treated check (Amaugo & Emosairue, 2003). Similar result was also reported by Islam *et al*. (2013) where neem extracts, *Azadirachta indica* at 15ml/L concentration reduced 38.38% & 58.08% dead heart and white head respectively. In addition neem was found to attract many predators (Dhuyo & Soomro, 2007).

It is obvious from the present study that *M. ferruginea* aqua extract in combination with Cow urine could also be effective in reducing infestation. This is because together with the enzymatic action of Cow urine and a complex bioactivity of the botanical, the mixture treatment (synergy) increase efficacy and may have significant fatal effect against the insect resulting in lower infestation on sorghum crop. This finding is in agreement with that of Barapatre and Lingappa (2003) who have documented similar results on effectiveness of cow urine along with various botanicals against *Spodoptera litura* (Fab.) and *Helicoverpa armigera* (Hub.) in groundnut and chickpea, respectively

In all the treatments lower numbers of larvae per plant were found at the higher rates. No larvae per plant were found on plots treated with powder and aqua extracts of *M. ferruginea* at the higher rate in three applications. Full deterrence recorded for higher rates of powder and extracts, suggesting that *M. ferruginea* might contain most of the volatile constituents which can be released at the higher rates completely protected the plant from insect feeding. High number of larvae feeding at the lower rates of these botanical treatments implies that the deterrence activities of *M. ferruginea* were lower at the lower rates.

Result showed that sorghum plots treated with the mixture exhibited significantly lower number of larvae as indicated by fewer larvae feeding on it at three applications. The possible explanation for this may be the odor or volatile from *M. ferruginea* that was high and in combination with cow urine the efficacy of the mixture increased (Synergism). The result of the study is comparable with the report of Shrinivas & Balikai (2009). However, it can also be noted that larvae feeding at all the rates and application times treated plants was considerably lower than that of the untreated control. These results agreed with Assefa Gebre-Amlak and Ferdu Azerefegne (1999) who reported that fresh and dried fruit extracts of Persian lilac at the rates 2, 10 and 20 kg/ha and 1, 2 and 10 kg/ ha were found to be effective in reducing the number of larvae per plant compared to the untreated control.

Numbers of dead larvae were highest in plots treated with the mixture at the higher rate (15%) with three times applications followed by plots treated with *M. ferruginea* seed powder at the higher rate (3g) with two applications. The increased efficacy of seed

powder extract of *M. ferruginea* may be the botanical work by ingestion through contact. Likewise, there was sufficient water or rain fall to moist the powder and reach at the site of action where small larvae ingest in attempting to feed on foliage. The reason for better efficacy of the mixture treatment on *C. partellus* mortality could be treatment insecticides efficacy increased as the treatments mixed and are more potent against this pest. Thus, in this study the addition of little soap to this treatment may sticks the toxic and antifeedant activity effect of *M. ferruginea* seed aqua extract and cow urine to the leaf surface, prevents the insect from feeding leading to death via starvation. This result agrees with the research results of Sisay Birhanu *et al*. (2019) who reported that combination of *A. indica* + Karate 5 EC was effective against larvae of Fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) with in the second-round spraying. The positive correlation recorded on the dead larvae at different treatments, rates and frequencies indicated that mortality increases as the rate increases with increasing applications. Negative correlation indicated that density of larvae decreases as the rate increases or viceversa. Zero correlation indicates that the density of larvae has no relations with the rate and times of applications.

Plant heights on treated plots were increased as compared with the untreated plots. However, result indicated that in all the treatments height of plants at the higher concentrations sprayed were significantly longer than that of the lower rate and the untreated control implying that the persistence effect of this botanical may be produced from the higher dose and prevents the plant from insect damage. The current findings agree with the research results of Beniam Tilahun & Ferdu Azerefegne (2013) who stated that among the Milletia treatments height of 5% and 3% sprayed on maize plants was

significantly higher than that of 1% sprayed, but 1% sprayed plants were significantly taller compared to those from the untreated plots.

Stem exit holes were reduced at the higher rates with two applications in plots treated with *M. ferruginea* seed powder, the mixture treatment and *M. ferruginea* aqua extract. This implies that two applications of these treatments at the higher rate were sufficient to provide complete protection of sorghum from the larvae. The possible explanation could be natural insecticides with repeated applications at the higher doses may prevents the insect from further feeding or attack. However, there was no significant difference on larval tunnel length among the different rates and frequencies of all the treatments and the untreated plots. This might be that tunnels were made by the late instars larvae that hide in sorghum stem and protected from the treatments effect.

In the present study the exotic parasitoid, *C. flavipes* was recorded after rearing larvae of *C. partellus* in the laboratory. There was no significante difference among rates, frequencies and the untreated control in the wasp population. The reason could be that these treatments had no negative effect on the main natural enemy of this stem borer. The present findings agree with Ogah *et al*. (2011) and Basappa (2007) who reported that the use of botanicals had no negative effect on natural enemies as compared to synthetic insecticides. The presence of almost the same number of natural enemy, *C. flavipes* on treated and untreated plots indicates that these plant and animal-based insecticides are less toxic and might be compatible with biological controls in sorghum fields. Similar result has been reported by Dhuyo & Soomro (2007) on efficacy of plant extracts against

yellow rice stem borer studies. In their studies maximum number of different predators was found in neem extract treated plot.

Result of the present study showed that plant and animal-based insecticides increase sorghum yield by lowering the population of *C. partellus* in the filed. The highest yield of sorghum was obtained in plots treated with *M. ferruginea* seed powder followed by the mixture and *M. ferruginea* seed aqua extracts at the higher rates and two and three times applications. The good performance with respect to yield by these treatments was due to the suppression of the pest population which has contributed towards increase in sorghum yield. Similar results has been reported by Asmare Dejen (2008) where physic nut seed powder, pyrethrum flower powder, tobacco leaf powder, neem seed powder and ***E.*** *schmperiana* leaf powder at the rate of 0.65-1.0g and frequency of 3-4 times application resulted in yield increment of 46-69%, 48-55%, 51-56%, 31-53%, and 39-57% of sorghum over the untreated control, respectively. Similarly higher yield was protected from *B. fusca* attack by *M. ferruginea* treatment. The highest (97%) yield was obtained from plots treated with *M. ferruginea* at 5% concentration (Beniam Tilahun & Ferdu Azerefegne, 2013).

6.5 Conclusion

This study clearly indicated that all insecticides tested were effective in reducing sorghum infestations under field condition. *M. ferruginea* seed powder showed higher efficacy in suppressing *C. partellus* infestations with significant larval mortality at the higher rate with two times applications. Likewise, aqua extract of *M. ferruginea* and the mixture were effective in reducing leaf damage, dead hearts and larvae abundance per plant and caused significant larval mortality at the higher rates with three times applications. However, all these treatments had no negative effect on the main natural enemy of this stem borer, *C. flavipes*. The present study confirms that *C. partellus* infestations and all its activities can be protected in the field with biopesticides, without affecting the natural enemy of this pest. Hence it can be concluded that plant and animal-based insecticides at the higher rates with two and three applications were best in controlling *C. partellus* infestations in the field.

Chapter 7

General Conclusions and Recommendations

7.1 Conclusions

C. partellus was found dominant on cultivated sorghum and wild host plants all over the study area of Kalu (south Wollo), Bati and Dawa Chefa districts (Oromia special zone) of Amhara adimnstrative region. Its pest status has been increased in cultivated crops. From the present study it was possible to see that the incidence of *C. partellus* was at its peak during the early stages of sorghum and the lowest was at maturity stages. Variability in the occurrence of this pest was also observed across the districts with Bati and Dawa Chefa having the highest as compared to Kalu. The rate at which *C. partellus* has spread in all the study areas is a reminder that status of this insect pest has become increasing in all the areas on sorghum. The range of this pest increased from the previous years and to the high altitudes of south Wollo zone, Kalu district. Infestation was almost high in all the surveyed districts. Moreover, the level of infestation was higher in the lower growth stages of sorghum.

Ants, spiders, earwigs, ladybird beetles and *C.flavipes* were the most important natural enemies of this pest found dominant in all areas. *C. partellus* was found attacked by these natural enemies in different growth stages of sorghum and wild host plants. The exotic larval parasitoid of this pest, *C. flavipes* was found to be dominant in all the study areas being highest in Bati and Dawa Chefa districts. However, the other exotic pupal parsitoids of *C. partellus*, *X. stammator* was not recorded during the study.

Among the various botanicals evaluated in the management of spotted stemborer birbira, *M. ferruginea* powder, aqua extract and a mixture of *M. ferruginea* and cow urine showed good efficacy in the laboratory. In the present study these treatments were tested in the field at three rates and two level frequency applications against *C. partellus* infestations on sorghum. The study result showed *M. ferruginea* powder with two and the others with three times applications at the higher rates significantly decresed *C. partellus* infestations and larval density with high larvae mortality. The effect of these insecticides on the natural enemy of *C. partellus* was minimal. Therefore, it was recommended that plant animal-based insecticides are used as a management option of *C. partellus* as components of integrated pest management. Thus, a detailed study with different concentrations and frequency of applications with other bioagents has to be carried out.

7.2 Recommendations

- Taking the current distribution of the exotic *C. partellus* at Kalu, Bati and Dawa Chefa districts of north eastern Ethiopia in to account, its country wide distribution should be known.
- In south Wollo (Kalu) and Oromia (Bati and Dawa Chefa) zones natural enemy specieses are too abundant and the relationship between these natural enemies and sorghum insect pest, *C. partellus* is to be studied in detail.
- It was known that early stages of sorghum were highly susceptiable t*o C. partellus* infestations in all the surveyed areas. Thus management options should be undertaken at these stages by taking all the necessary precautions.
- The role played by the natural enemies against this pest is extremely important. So future study on the control of this pest should be focused on the integration of both biological and plant and animal-based insecticide through judicious use of insecticides and conservation of natural enemies.
- The lesser exploited natural products (botanicals and animal products) can be either used alone or in combinations and as part of Integerated Pest Management (IPM) in managing the spotted stem borer, *C. partellus*.
- Since succeful implementation of sorghum stem borer, *C. partellus* management is required in the region further evaluation on the formulation, efficacy, rates and frequencies of application are necessary.

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APPENDICES

Appendix 3.1 Total number of stem borer species recorded on cultivated plant during 2016/17 and 2017/18 crop growmg seasons

Locations	Years or seasons	Composition (%)			
		No borers recovered	*C. partellus*	*B.fusca*	*S. calamistis*
Kalu	2016/17	105	73	27	5
	2017/18	117	86	31	0
Bati	2016/17	169	161	8	0
	2017/18	121	118	3	0
Dawa chefa	2016/17	140	140	0	0
	2017/18	148	148	0	0

Appendix 3.1b Total number of stem borer species recorded on wild host plants during 2016/17 and 2017/18 crop growmg seasons

Locations	Years or seasons	Composition (%)			
		No borers recovered	*C. partellus*	*B.fusca*	*S. calamistis*
Kalu	2016/17	7	3	4	-
	2017/18	6	3	3	-
Bati	2016/17	2	1	1	-
	2017/18	2	2	-	-
Dawa chefa	2016/17	2	1	1	-
	2017/18	5	4	1	-

Plate 3.1 adult *C. partellus* moth *B. fusca* *S. calamistis moth*

Appendix 3.2 Stem borers recovered during the survey

Appendix 3.3 Sample leaf damage score sheet
Locations: Kalu, Bati and Dawa chefa…….
Farmer Name…….
Field Number ……
Plant stage …….

Plant number	Damage scores	Stem borer species			Natural enemies recovered
		Cp	*Bf*	*Sc*	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Key: Stem borer species: *Cp = Chilo partellus, Bf= Busseola fusca, Sc = Sesamia calamistis*

Damage Score: 1= 1-20 %, 2= 21-40 %, 3= 41-60 %, 4= 61-80 %, 5= over 81 %

Appendix 3.3.1 ANOVA table for leaf damage across the locations

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	106.889	2	53.443	34.357	P<0.000
Within Groups	9.3333	6	1.5556		
Total	116.228	8			

Appendix 3.3.1b ANOVA table for leaf damage at two growth satges

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	20.2	2	10.11	3.95	0.08
Within Groups	15.33	6	2.556		
Total	35.56	8			

Appendix 3.3.2 ANOVA table for stem holes at vegetative stages across the districts

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	1149.56	2	574.778	24.75	P<0.001
Within Groups	139.33	6	23.22		
Total	1288.89	8			

Appendix 3.3.2b ANOVA table for stem holes at maturity stages

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	504.22	2	252.11	10.65	P=0.01
Within Groups	142	6	23.667		
Total	646.22	8			

Appendix 3.3.3 ANOVA table for stem tunnel length at vegetative stages across locations

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	38.223	2	19.112	18.2	P<0.002
Within Groups	6.305	6	1.051		
Total	44.528	8			

Appendix 3.3.3b ANOVA table for stem tunnel length at maturity stages

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	22.42	2	11.211	9.7	0.013
Within Groups	6.934	6	1.155		
Total	29.356	8			

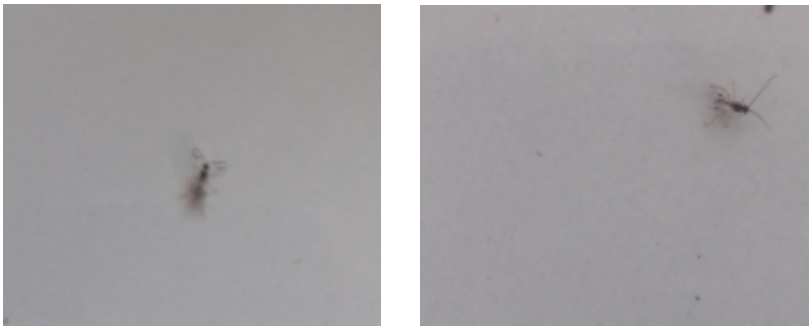
Appendix 4.1 Total number of *C. partellus* parasitods recorded during the two growing seasons

Parasitoids recorded from cultivated (Sorghum) plants												
Growing seseons	Locations											
	Kalu				Bati				Dawa chefa			
	egg	larva	pupa	total	egg	larva	pupa	total	egg	larva	pupa	total
2016/17	5	21	03	29	13	24	0	37	20	30	02	52
2017/18	25	24	02	51	22	42	0	64	11	35	02	48

Appendix 4.2 *C. partellus* parasitoids recovered during the survey

Cocoon mass of *C. flavipes*

Adult *S. parasotica*



Adult *C. flavipes*

Appendix 4.3 Number of *C. flavipes* emergence from *C. partellus* attacking sorghum at heading and maturity grwth stages

2016/17 Locations	Plant stages	Larvae reared	Parasitized larvae (L. with cocoons)	% Parasitized larvae	% reared	No. parasitoids emerged
Kalu	Vegetative	4	-	-	75.0	-
	Heading	12	2	16.6	73.9	14
	Maturity	13	3	23.0	80.0	28
Bati	Vegetative	10	1	10.0	64.7	-
	Heading	16	6	37.5	72.2	31
	Maturity	10	7	70.0	100.0	49
Dawa Chefa	Vegetative	7	1	14.2	71.4	5
	Heading	14	5	35.7	75.0	35
	Maturity	11	7	63.6	77.2	27
2017/18						
Kalu	Vegetative	3	-	-	50.0	-
	Heading	18	3	16.6	87.5	17
	Maturity	15	6	40.0	88.2	25
Bati	Vegetative	11	2	18.2	68.4	9
	Heading	14	9	64.2	71.0	37
	Maturity	16	9	56.2	73.9	53
Dawa chefa	Vegetative	5	1	0	62.5	-
	Heading	19	7	36.8	76	31
	Maturity	13	6	46.1	80.9	40

Appendix 4.4 *C. partellus* predators recovered during the survey

Earwig

Ladybird beetle

Appendix 4.5 Bigger cages and plastic beakers for rearing of stem borers

Biger cages for rearing of stem borers

Plastic beakers for rearing of stem borers

DECLARATIONS

I, hereby declare that this PhD Dissertation is my original work and has not been presented for any degree in any other University, and all sources of material used for this dissertation has been duly acknowledged.

Name: Adem Nega Yimer

Signature_____

Date _____

This PhD Dissertation is submitted for examination with my approval as an advisor.

Name: Emana Getu Degaga (Professor)

Signature_____

Date _____