ASSESSMENT OF AWARENESS AND INCIDENCE OF COFFEE BERRY BORER *(Hypothenemus hampei* Ferrari*)* UNDER PLANTATION AND GARDEN COFFEE MANAGEMENT SYSTEM IN YEKI AND MENGESHU WOREDAS, SOUTH WESTERN ETHIOPIA

M.Sc. Thesis

By

Eyasu Asfaw Tegegn

June, 2013

Jimma University

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M.Sc. Thesis

Submitted to the School of Graduate Studies
Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Horticulture (Coffee, Tea and Spices)

By

Eyasu Asfaw Tegegn

June, 2013
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DEDICATION

This thesis manuscript is dedicated to my beloved wife, W/ro Amarech Dejene and esteemed daughter Saron Eyasu for all the sacrifices, wishes and praiseworthy to my success in all my endeavors.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bona-fide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at Jimma University, College of Agriculture and Veterinary Medicine and put at the University Library to be made available to borrowers under the rules of library.

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Name: Eyasu Asfaw Tegegn Signature: ____________________

Place: Jimma University, Jimma

Date of Submission: June, 2013

BIOGRAPHICAL SKETCH

Eyasu Asfaw Tegegn was born at Teppi, Yeki woreda; previous Illubabor province on July 18 in 1963. He attended elementary at Teppi elementary school and Flege-yordanose Elementary and Junior Secondary Schools in Addis Ababa and his senior secondary school at Abyot-Kerse and Shemelis-habte Comprehensive Secondary Schools in Addis Ababa. Later on, he joined Jimma College of Agriculture in 1982 and graduated in 1984 with a diploma in the field of General Agriculture.

In September 1984, he was employed in the former Coffee and Tea development Minstery and served as crop production and protection expert in Gumay and Seka woreda of the former Illubabor and Kaffa provinces, respectively. As of 1993, he was then transferred to Southern Nations Nationalities and Peoples Regional State (SNNPRS) in Bench Maji zone to serve as crop protection expert. He further attended the summer in-service training program at Jimma University College of Agriculture and Veterinary Medicine for five consecutive summers and graduated in September 2007 with B.Sc. Degree in Agriculture (Horticulture).

Since graduation he has been serving in Mizan Plant Health Clinic, under regional Bureau as an Entomologist until July 2010 when he joined the school of graduate studies of Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) summer program to pursue his postgraduate studies leading to Master of Science degree in Horticulture (Coffee, Tea and Spices). Currently he is married and a father of one daughter.

ACKNOWLEDGMENTS

First of all, I would like to thank my God for his endless help that enabled me complete this research work successfully. I am particularly grateful and would also like to express my heartfelt appreciation to my advisors Dr. Ali Mohammed and Mr. Esayas Mendesil for their constructive advice, guidance, encouragement, material support, willingness to supervise my research and their valuable comments from early stage of proposing the research work to the final thesis write up, which helped me in timely and successfully completing my study.

I am highly indebted to Mizan Plant Health Clinic for paying my education fee and salary during my study leave. Also my special thanks go to Miss Hibret Asfaw for her tireless support in writing my research proposal and thesis manuscript and Mr. Wegene Ambelo for his support during my research laboratory work. I express my sincere feelings and appreciation to Mr. Amsalu Nebyu, Mr. Chemeda Abedeta and Mr. Worku Tefera for their constructive advice, material support and assistance during data analysis.

I would like to acknowledge all staff members and Teppi-Kabo coffee plantation enterprise for their kind permission to use their coffee plantation for my research work and providing me with material and transportation support without any payment. I also extend my thanks to Mr. Gemeda Nemesa for his positive response to what I asked him for. I am thankful to Godre zone and Yeki woreda for providing me with secondary data during my research work. Also my special thanks go to Mr. Yared G/Maryam for providing me secondary data and Mr. Solomon Asfa and Mr. Azemera Alalo for their assistance during data collection from field and coffee processing factories.

I also would love to express my heartfelt gratitude to my Wife Amarech Dejene, my daughter Saron Eyasu and Yimenashu Dejene for their constant moral support and encouragement during the course of my study and specially, Miss Amarech Dejene for her responsibility in looking after me and my family by avoiding my concern about caring of them have contributed a lot to the success of my study. Finally, my heartfelt appreciation also goes to my family members, Dr. Shibru Asfaw, Miss Menen Asfaw and Mr. Tilahun Asfaw for their endless encouragement, moral and financial support during my study period.

TABLE OF CONTENTS

CONTENTS **PAGE**

LIST OF TABLES **PAGE**

LIST OF FIGURES **PAGE**

LIST OF TABLE IN THE APPENDIX **PAGE**

LIST OF PLATES **PAGE**

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CABI	Center for Agriculture and Bioscience International
CBB	Coffee Berry Borer
DA	Development Agent
EARO	Ethiopian Agricultural Research Organization
ECX	Ethiopia Commodity Exchange
EIL	Economic Injury Level
FAO	Food and Agriculture Organization of the United Nations
FCP	Forest Coffee Population
ICO	International Coffee Organization
IPM	Integrated Pest Management
JARC	Jimma Agricultural Research Center
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
LSD	Least Significant Difference
m.a.s.l.	Meters Above Sea Level
MoA	Ministry of Agriculture
PLC	Private Limited Company
SAS	Statistical Analysis Software
SNNPRS	Southern Nations Nationalities and Peoples' Regional State
SPSS	Statistical Package for Social Science
USD	United States Dollar
USDA	United States Department of Agriculture

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By

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ABSTRACT

*Coffee berry borer is one of the important insect pests known to cause considerable yield loss in Ethiopia. Therefore, the present study was designed to assess the level of infestation of coffee berries at different developmental stages under garden and plantation management systems. A 3*2*4 factorial experiment was carried out at three locations (Baya, Shone and Anderacha kebele in southwestern Ethiopia), under two management systems(Garden and Plantation) and four coffee berry development stages (Red ripe, Dried over ripe, Fallen and Dried left over cherries) with three replications. A purposive sampling technique was followed to select the woredas and Kebeles while fruit assessment was done on 300 randomly selected sample fruits from each sampling plot. Moreover, perception, knowledge and management practices of 200 randomly selected farmers, 30 DAs and 24 experts of Teppi coffee plantation enterprise were assessed. The results revealed that there was a significant interaction (p<0.0001) between location and berry development stage and berry development stage with management systems. Significantly the highest proportion of damaged berries (37.5%), number of holes per bean (10.88), weight loss of berries (8.11%), number of larvae (4.11), and number of adults (7.55) were observed on dried leftover cherries at Baya (1110m.a.s.l) while the highest percentage of discolored beans (64.91%) was obtained from fallen berries at Anderacha (1720m.a.s.l) and the highest mean damage (24.51%) and weight loss (4.86%) was recorded for dried leftover cherries under plantation coffee management system. On contrary, the lowest mean 0.50, 0.83, 0.17, 0.00, and 0.63 % of damaged berries, number of holes per bean, weight loss, number of larvae on red ripe cherry and number of adults per cherry were recorded at Shone on fallen berries, respectively, but no damage of CBB was observed on red ripe cherries at Anderacha. Both mean number of eggs (2.44) and pupas (0.50) were higher at Baya on dried leftover cherries, but lowest mean number of eggs (0.76) and pupa (0.08) were recorded at Anderacha on red ripe cherries. Results of the current study showed highest coffee berry borer damage and its effect on dried leftover cherries at Baya and less on red ripe cherries at Anderacha. Despite this fact, 87% of coffee farmers, 53.30% of DAs and 29.20% experts of the enterprise had no prior knowledge about the typical symptom of CBB damage and only 13.3% of DAs and 25% of the experts of enterprise applied/assisted CBB control measures. Therefore, early and effective harvesting of red ripe cherries, growing at higher elevation (above 1400m.a.s.l), removal of dried leftover cherries and creating awareness/training among stakeholders pertaining to CBB and its controls are important components to manage the damage of coffee berry borer.*

Key words: Coffee berry bore; Damage; Infestation; Knowledge; Perception; Yield loss

1. INTRODUCTION

Coffee is a member of the large *Rubiaceae* family, which constitutes the genus *Coffea*. The Genus *Coffea* consists of 103 species (*Davis et al.*, 2006). The two main species exploited in the world at the present time are *Coffea arabica* L. and *Coffea canephora* pierre while other species are being cultivated less extensively (Coste, 1992). Arabica coffee has its center of origin in the highlands of southwest Ethiopia where wild coffee populations naturally occur in the aforaminate rain forests at altitudes between 1,000 and 2,000m above sea level (m.a.s.l.) (Crowe, 2004). Ethiopia is believed to have a high diversity of Arabica coffee and the wide climatic and soil factors offer the country to grow diverse types of Arabica coffee (Fekadu *et al*., 2008)

Coffee is the back bone of Ethiopian economy which is accounting for about 60% of the national economy, 30% of government direct revenue and over 35% to national foreign revenue (FAO, 2006). Moreover, about 25% of the population of Ethiopia also depends on coffee directly or indirectly through production sales/income, coffee processing, transport and marketing or commercial services (Nigussie *et al.*, 2007).

In Ethiopia, the total area of land devoted to coffee production is estimated 800,000 hectares, of which 496,000 hectares are to be productive (Tadesse *et al.*, 2008) and average annual production of 350,000 tons of clean coffee produced in three broad categories of production systems. Out of the total area coverage, about 50,000 ha (8.30%) is considered as forest coffee, semi-forest coffee covers about 180,000 ha (30%), garden coffee accounts for 56.70% and 5% is categorized as modern coffee owned plantations (Alemayehu *et al.*, 2008).

In Ethiopia, Oromia and the Southern Nations Nationalities and Peoples Regional States are sharing the largest volume of coffee production. On the other hand, western, southern and eastern parts of Ethiopia represent about 46, 44 and 10% of coffee production, respectively (Morten, 2012). Ethiopia stands first in Africa and third in the world in production of Arabica coffee (ICO, 2012a and 2012b).

Ethiopia is not using its full potential as expected in terms of coffee production due to several natural and socio-economic constraints such as increasing population pressure, deforestation, expansion of large scale farms, competition from other crops, climatic change and pest damages are some of the constraints (Fekadu, 2008***;*** Solomon *et al*., 2008). Insect pests are among the number of factors considered to limit coffee production, both in terms of quality and quantity (Million, 2000).

The common insect pest of coffee in Ethiopia include boring beetles, scale insects and mealy bugs, other Hemiptera including Antestia, Lepidoptera miners and defoliators, every part of the coffee tree including roots, stem, leaves, flowers, berries and the seed in storage may all be attacked by insects (Wrigley, 1988). In Ethiopia, over 47 species of Arthropod pests are known to attack coffee (Million, 2000). Among those species only a few species cause considerable damage to demand control measures. One of the identified potentially important insect pests that are known to cause damage on coffee is coffee berry borer (CBB) (Esayas *et al*., 2008).

Coffee berry borer is endemic to Central Africa and now it is found in all coffee producing countries. It is one of the major pests of coffee which cause considerable amount of loss throughout the world (Le Pelley, 1968). CABI (2006) has reported that attack caused by CBB can result in premature fall of berries and hence total crop loss, also in other cases the berries may remain attached until harvest but the beans are reduced in weight, of lower quality and their flavor is adversely affected. Coffee berry borer is relatively a recent problem in Ethiopia and Latin America. A field survey of Ethiopia’s coffee growing regions conducted in the late 1960s found no trace of the beetle, but in 2003 researchers reported that the pest was wide spread (Westly, 2010).

In Ethiopia the first incidence of CBB was reported by Davison (1968) as cited by Esayas *et al.* (2003). The CBB used to be considered as a minor pest or cause a little damage to coffee for a long time, but a survey conducted in some coffee growing areas showed mean percentage infestation of 13.3% to 61% on dry left over coffee berries (EARO, 2000). However, little has been done to regarding the extent and type of damage by CBB in different locations and with due consideration given to berry development stages with the intent of devising appropriate management system is very few. Also the perception, knowledge and management practices of extension service providers (DA) and farmers regarding borer are generally not assessed. Hence, the current study was initiated to contribute in filling the gap of research.

Therefore, the objectives of the study are:

- To assess the level of infestation caused by CBB under different management systems and locations,
- To assess perception, knowledge and management practice of farmers, development Agents and different experts with regard to the control of CBB

2. LITERATURE REVIEW

2.1 National and global scenario of coffee production

Coffee is the major species of the family *Rubiaceae*, which includes some 500 genera and 600 species, of which the most economically important genus by far is *Coffee*. They are mainly found in the lower regions of the tropical rainforest (Wrigley, 1988; FAO, 2006). From the genus *Coffea*, the two main species exploited in the world at the present time are *Coffea arabica* L. and *Coffea canephora* pierre. Other species of coffee are being cultivated less extensively. Arabica coffee is the species that has been known for the longest time and is also the most wide spread throughout the world. The species *C. canephora* takes second places in the world next to *C. arabica.* It is mostly grown in Africa and Indonesia and is also being cultivated quite successfully in northern Brazil. In this region, the climate, which is hot and humid, is not favorable for growing *C. arabica* (Coste, 1992). *C. arabica* L. (80%) and *C. canephora* (20%) are dominating the world coffee production and marketing (FAO, 2005).

Arabica coffee has its center of origin in the highlands of south-west and south-east Ethiopia where wild coffee population grow naturally in the under growth of the afromontane rain forests at altitudes between 1000 and 2000m.a.s.l. (Tadesse *et al.*, 2008). Because of suitable agro-ecology in Ethiopia the coffee can also grow at very wide ranges of altitude from 600m.a.s.l. in Gambela region to 2200m.a.s.l. at certain location in southwest and south Ethiopia (Paulos and Tesfaye, 2000). *Coffea arabica* drives from two varieties, namely var. Arabica and var. Bourbon. Variety Arabica is presumed to have originated from the native Ethiopia *C. arabica,* which was subsequently distributed into cultivation from the Yemen while variety. Bourbon arose as a spontaneous mutant from Ethiopia cultivated by the French upon Reunion (Wrigley, 1988).

The coffee plant takes approximately 3 to 4 years to develop from seed germination to first flowering and fruit production. The fruit of the coffee tree is known as a cherry (berry), and the beans which develop inside the cherry are used as the basic element for producing roast and ground coffee, soluble coffee powders and coffee liquor. Trees are in full bearing after six to eight years. Yields increase steadily until the age of 15 years and the trees are bearing on average twice as much as they did when four to five years old (Wrigley, 1988). The same author reported that in Brazil good yields are expected for 15 to 18 years, after which they decline, becoming unproductive at 20 to 30 years due to soil exhaustion, soil erosion and nematodes. In Ethiopia, there are different coffee production systems, which range from undisturbed (wild) state with no management to very intensive management of production (coffee farms owned by private sectors) and are broadly grouped as forest, semi-forest, garden, and plantation production systems. The first two production systems mainly based on naturally occurring forest coffee with little and/or limited management practices. In the forest coffee, which is also referred as wild coffee, coffee regenerates in natural forests as understory plant without human intervention. The semi-forest production system, which also referred as semi-wild coffee, the involves intervention of human by thinning the over story forest trees and the ground vegetation (Gole *et al.*, 2002).

In Ethiopia about 92-95% of the coffee production is produced by the smallholder farmers with a coffee farm area of less than 2 ha per house hold, while the rest 5-8 % is of large scale type, which is owned by the state. The coffee production system is generally known to be organic, which means the production system uses no or very small amount of external inputs like inorganic fertilizer and fungicide chemicals. The coffee production system has always been characterized as a low input and low output agriculture, with its yielding level per hectare standing at the lowest rank in the world (Admasu *et al.*, 2008). Economically, coffee is an important crop that serves directly or indirectly as a means of livelihood for a large number of populations including the families of about one million-smallholding coffee growing peasants and it contributes a significant amount to government revenue. Its basic importance to the nation is the role it plays as the mainstay of foreign trade (Alemayehu *et al.*, 2008).

The largest volume of coffee is grown in the two regions, Oromia (in the central part of the country) and the Southern Nations Nationalities and Peoples Region (SNNPR) (USDA, 2012). The West Ethiopia represents about 46% of Ethiopia’s total production. It includes regions like Jimma, Kaffa, Illubabor, Wellega, Bench Maji and others. In South Ethiopia, Sidamo and Yirgacheffe represent 44% of the total Ethiopian coffee production. In East Ethiopia, Harar accounts for 10% of Ethiopia’s coffee production (Morten, 2012).

Global coffee production has been averaged around 6 million tons a year during the 1990s, and increased to 8.05 million tons in 2010. Coffee is grown in more than 70 countries but over 64.5% of the world's coffee is produced by five of them Brazil (34%), Vietnam (14%), Colombia (7%), Indonesia (7%) and Ethiopia (4.5%). Brazil has long been the world's largest coffee producer, with an average annual production of 2.5 million tons in 2011. Vietnam is next (1.1 million tons) followed by Colombia (560,000), Indonesia (560,000), Ethiopia (390,000), India (280,000), Mexico (270,000), Guatemala (230,000), Honduras (230,000), Peru (219,000), and Uganda (190,000) (Fairtrade, 2012; ICO, 2012a). Currently, Ethiopia is a leading coffee producer in Africa fallowed by Uganda, Côte d'Ivoire, Cameroon and Tanzania. But, Ethiopia is the second largest coffee exporter next to Uganda in Africa (ICO, 2012b).

2.2 Major constraints of coffee production in Ethiopia

Even though Ethiopia is the home of Arabica coffee with high genetic diversity, the national average yield has not exceeded 500 or 600 kilogram per hectare and this is lower as compared with other coffee producing countries. The total production from the estimated area of about 800, 000 hectare has never exceeded 350,000 tones until recently (Alemayehu *et al.*, 2008). Although there is a considerable improvement in both the area and amount of annual production, generally the coffee industry is facing a complex set of problems that require urgent attention from policy makers, researchers and development workers. The problems are basically related to production, processing and marketing (Solomon *et al*., 2008).

Limited research intervention, limited supply of improved coffee cultivars, lack of improved local varieties for each of the very diverse coffee ecologies of the country, poor management practices (including weeding, shade regulation, spacing and density), absence of the use of chemical fertilizers and poor productivity potential of most coffee landraces, environmental degradation, deforestation, conversion of forests to agricultural and grazing lands and expansion of commercial plantations (for example, tea) are major constraints to coffee production (Alemayehu *et al.*, 2008; Fekadu, 2008***;*** Solomon *et al*., 2008; Kucel, *et al.*, 2009). The same authors have reported that, those constraints together with aging of plantation, very weak linkage among research-extension services and producers, socio-economic problems within smallholders to adopt improved technologies and pest problems have greatly contributed to poor coffee production performance in the country.

2.3 Insect pests of coffee

Coffee is an evergreen perennial crop grown in climates without severs extremes, consequently pests can survive from year to year and fortunately the same applies to the parasites and predators of these pests (Wrigley, 1988). According to the review of Le Pelley (1973), more than 850 species of insects are known to feed on coffee: of these pests, 34% are Coleoptera, 28% Hemiptera, 21% Lepidoptera, 6% Orthoptera, 6% Hymnoptera, 3% Diptera, 3% Tysanoptera, and 1% Isoptera.

Wrigley (1988) described that the major pests of coffee including boring beetles, scale insects, mealy bugs, other Hemiptera including antestia, lepidopterous miners and defoliators which attack every part of the coffee roots, stem, leaves, flowers, berries and the seeds in storage in some growing area. Coffee farms are continuously threatened by a range of pest and disease problems. Many of these are minor in terms of the damage they cause and their effect on yield and quality. However, some can be very serious indeed and can have a major impact not only on individual farmers but, on the economy of countries or regions heavily dependent on coffee for foreign exchange earnings (CABI, 2006).

Arabica coffee, which originated in Ethiopia, is one of the most valuable crops for the country. But, the damage caused by some coffee insect pests is among the number of factors considered to limit coffee production, both in quality and quantity (Million, 2000). According to Million (2000) and Esayas *et al.* (2008), in Ethiopia, over 47 species of Arthropod pests have been recorded on coffee and only a few species cause considerable damage. One of the possible reasons is the existence of natural enemies (parasitoids, predators and insect pathogens) which keeps the population at a low level, mainly in the relatively undisturbed coffee ecosystem. In addition, the genetic diversity of Arabica coffee in the country coupled with cultural practices with minimum or no impute used by subsistence farmers (Tsegaye *et al.*, 2000) may have also contributed for suppression of insect pests of coffee. Nevertheless, if there are change in cultural (agronomic/farm) practices that may affect the balance between pests and natural enemies may lead those minor pests becoming more economical important and can cause serious problem to coffee industry (Esayas *et al.*, 2008).

According to the review of Million (2000), insect pests of coffee in Ethiopia can be categorized based on the extent of damage they cause as major important insect pests, which include antestia bug, *Antestiopsis intricata*, *Antestiopsis facetoides,* and coffee leaf blotch miner, *Leucoptera caffeina* that cause considerable damage. Secondly, potentially important insect pests such as coffee berry borer (*Hypothenemus hampei*), coffee thrips (*Diarthrothrips Coffeae*), green scale (*Coccus alpinus*) and coffee cushion scale (*Stictococcus formicarius*) that are potentially important pests and finally, minor important insect pests such as black borer, giant looped, coffee bark scale, white waxy scale, dusty brown beetle, black thread scale, cossid stem borer, etc that are considered as rarely found insect pests of coffee. The Coleoptera includes some important insect pests. Among Coleoptera, the most severe and widespread being the scolytidae, called coffee berry borer, *Hypothenemus hampei*, which is indigenous to Africa and has been exported to nearly all parts of the tropics, in Brazil it has caused vast losses and is still a most serious pest (Le Pelley, 1973).

2.4 Coffee Berry Borer /*Hypothenemus hampei*/

2.4.1 Origin and distribution

Coffee berry borer, first described in 1867 from a specimen in a traded coffee and recorded in the field in Gabon in 1901 (Chevalier, 1947 as cited in Wrigley, 1988), and in Zaire in 1903 (Murphy and Moore, 1990). Then, CBB become a major pest of coffee worldwide and it has spread to nearly all the major coffee producing counties of the world from its origin Africa (Le Pelley, 1968; Baker, 2000). In Ethiopia, the problem of CBB is relatively a recent occurrence; however its incidence was first reported from Mizan Teferi area, in the previous Keffa administration region by Davidson (1968) as cited by (Esayas *et al.* 2003).

According to the review of Vega *et al.* (2009), CBB is considered to be the most devastating pest of coffee. This pest occurs in tropical Africa, Asia, Mexico, South America (Colombia, Argentina and Brazil), Central America (Guatemala, Elsavador, Honduras and Costa Rica), and in the Caribbean (Dominican Republic and Jamaica). This small beetle can now be found throughout every coffee producing region, with the exception of Hawaii, Nepal and Papua New Guinea (Vega *et al.*, 2009).

The borer has expanded its distribution along with the extension of coffee plantation worldwide; altitude showed a marked effect on the distribution of the borer (Baker *et al.*, 1989). Le Pelley (1968) stated that, coffee berry borer is a serious pest of low altitude coffee, and almost disappears at the higher altitude at which coffee is grown as a major crop. Also Baker *et al.* (1989) reported that the optimum temperature range for the borer is about 23 to 25^{o}C (mean annual), and low altitudes have lower rainfall with a long dry season which may its intolerance survival.

According to the review of Million (1998) as cited by Damon (2000), the borer was found at all altitudes from below 1000 m to over 1900 m, in the major coffee growing areas in the south and south-west of the country, with relatively higher infestation at lower altitudes. This situation could indicate a recent introduction of the pest or a very effective control of the borer by natural enemies or plant resistance, which would then suggest that *H. hampei* has co-existed with Arabica coffee for a very long time in Ethiopia, possibly originated there. In Kenya it has been reported that CBB occurs at altitude of up to 1880m.a.s.l. on Arabica coffee with 1650m.a.s.l. as more conducive for the establishment of the pests (Mugo, 2008). Esayas *et al.* (2004) have also described that the study conducted in South Western Ethiopia region indicates the borer has been found to occur from 1200 to 1770m.a.s.l. Regression analysis showed that the incidence of *H. hampei* and altitude had significant negative relationship (Chemeda *et al.*, 2011).

2.4.2 Classification, morphology and biology

Coffee berry borer found in the kingdom: Animalia, phylum: Arthropode, class: Insecta, order: Coleoptera, family: Curculionidae/scolytidae, genus: *Hypothenemus, and* species*: hampei.* Its binomial name is refered as *Hypothenemus hampei* Ferrari *(*syn. *Stephanoderes coffeae Hagedom*), also commonly named as coffee berry borer, Berry borer (Wrigley, 1988; Damon, 2000)

The morphology of *H. hampei* are described in detail by Le Pelley (1973), Wrigley (1988), Waterhouse (1998), Damon (2000) and Jaramillo (2006). According to these reports, the adult female of coffee berry borer very small about 1.4 –1.7mm lengths, but some of them may reach 2mm. The coloration goes from blackish to brown or complete black. Prothorax is humped, and the head is concealed under the prothorax making its visible from above. The antennae are short, elbowed and clubbed. Elytra are striate and punctuate usually covered with short bristles. The emerging adults are brown, and they turn completely black within four to five days.

According to the review of Wrigley (1988), the female berry borer continues to bore and lays its egg until it is necessary to bore into the bean, over a period of three to seven weeks each female lays in the galleries cut into the hardened maturing bean, 30 to 60 eggs in batches of 8 to 12. Also Waterhouse (1998) describes that, the eggs are laid at the rate of two to three days in a batches of 8 to 12 over a period of four to seven weeks and each female produces from about 30 to over 70 eggs. On the other hand, Jaramillo (2006) reported that oviposition inside the galleries takes place over a period of 20 days; the female daily lays two to three eggs inside the berry. Similarly Esayas *et al.* (2005), in their review showed that oviposition started at about 7 to 12 days after the emergence of female borer and egg laying continued up to 10 to 20 days. The number of eggs laid per female per day ranges from 2 to 3 eggs with the total of 20 to 40 eggs per female. The incubation period of egg ranged from 5 to 10 days.

The larvae of CBB are legless, white with brownish heads, feed off the bean, making a side gallery off the tunnel. The male larvae feed for about 15 days and molt once. But, female larva feed for about 19 days and molt twice (Wrigley, 1988). Waterhouse (1998), indicated that insect has pupated without any cocoon formation, in the galleries excavated by the larvae and pupal stage passed through in four to nine days. According to the reviewer the total period from egg laying to the emergence adult is takes 25 to 35 days and the adult males emerge from the pupa earlier than the females. The sex ratio on appearance of progeny is about 10 female to 1 male (Baker *et al.*, 1992).

According to the review of Wrigley (1988) and Waterhouse (1998), the adult males' hind wings are short and they do not fly, but remain in the bean. Each male can fertilize two females a day and up to 30 females in a life time which extend to 103 days. Females have been to live up to 282 days with an average of 156 days. There is time for a succession of seven or eight generation a year in low land growing area (Waterhouse, 1998).

2.4.3 Damage pattern of *H. hampei*

Coffee berry borer is a pest of both immature and mature coffee berries (Damon, 2000). According to the review of the same author and Wrigley (1988), an adult female beetle bores a circular hole about 0.8 mm in diameter mostly in the tip of the berry and enters near the outer end. It bores a short distance in to the bean before laying egg in the tunnel, the adult beetle does not eat the outside of the cherry as it makes the hole and remain in the bean during life time. According McNutt (1975) as cited by Waterhouse (1998), the damage by this beetle is to the endosperm of the mature beans, which may be extensively damaged or even completely destroyed and even light bored beans acquire a distinctive blue-green staining which significantly reduces their market value. The losses of CBB arise mainly by the developing larva feeding on the beans, in addition indirect loss of quality and quantity can also result from the activity of secondary pathogens and the fragmentation of beans during processing (Reid, 1983).

According to Baker and Barrera (1993) and Esayas *et al.* (2004), the number of adult borers on dry leftover berries (dry berries on trees) are higher than from fallen berries on ground, also abundance of the borers conceded with the availability of over ripe, dry leftover, and fallen berries of preferred hosts of the borer, and the existence of such berries either on the tree or on ground at all times contribute to the occurrence of the borer almost throughout a year. Damon (2000) reported that the boring into the endosperm and feeding activities of adults and progeny cause a reduction in yield and quality of the final products.

Surveys conducted in some coffee growing areas of Ethiopia showed that the mean percentage infestation could range from 13.3% to 61% on dry coffee berries (EARO, 2000). Similarly, according to the study of Esayas *et al.* (2003 and 2004), the percent damage berries under laboratory and field conditions indicated that, dry coffee berries showed significantly the highest percentage of damage followed by red ripe and green stage berries, with 27.3, 11.2 and 7.4 mean percent damaged berries in laboratory and 41, 1.4 and 0.4 mean percent damaged berries in field, respectively. In those survey areas, the mean percent damaged berries ranged from 8% to 60% and mean percent damage of dry leftover and fallen berries showed highly significant and positive correlation. On the other hand, Chemeda *et al.* (2011) described that the mean incidence of *H. hampei* was as low as only 8.38 and 4.98% on dried left-over and fallen berries under forest coffee populations, respectively.

According to Reid (1983), the crop loss due to CBB reaches up 80% and in Jamaica, at the final grading and finishing works, an average of 33.7% green beans were rejected on the basis of damage by *H. hampei*. Also, Le Pelley (1968) and Waterhouse (1998) reported that the infestation of coffee berry borer reaches up to 80% in Uganda, 84-96% in Congo, 60-80% in Brazil, 90% Malaysia and 90% Tanzania.

According to the review of Wiryadiputra *et al. (*2008), in Indonesia, CBB causes significant yield losses in terms of coffee production, but also reduces coffee bean quality, resulting in low productivity and poor quality of Indonesian coffee. On average, CBB infestation on Indonesian coffee is more than 20%, and it results in yield losses of more than 10%. With an average national yield of 448.3 kg/ha/year, yield losses per hectare and a total financial loss caused by CBB can reach more than 6.7 million USD. Reid and Mansingh (1985) reported that, in Jamaica, the total losses for the 1980/81 crop were estimated at 314,521kg (US$1,887,126). In Colombia, in 1994/5 CBB infested 650,000 hectares of coffee, and reduced national crop production by 1.5 million bags and cost an estimated US$ 100 million (CABI, 2006). Globally, annual losses caused by this pest have been estimated at over US$ 500 million (Vega *et al.*, 2002).

2.4.4 Host plants

According to Wrigley (1988), the CBB lives and breeds only in genus *Coffea* and it can attack both the economic species and the indigenous species in the forest. The reviewer also indicated that the beetle has been found in the pods of a number of legumes and in the seed and berries of other plants, but the appearance to be occasional and not breeding grounds for the beetles. Similarly, in their review, Johanneson and Mansingh (1984) concluded that *H. hampei* is monophagous which attacks only six species of the genus *Coffea*.

On the other hand, Damon (2000) described that the majority of the reports of host plants relate to feeding only, but it is useful to note that *H. hampei* is not specific to coffee plants, from various families can provide appropriate conditions for reproduction of the pest. Similarly, according to Le Pelley (1968) *Hypothenemus hampei* in addition to its regular hosts in the genus *Coffea*, it has been reported from fruit, pods or seeds of species of *Centrosema*, *Crotalaria Phaseolus and Tephrosia* (*Fabaceae*), *Leucaena* (Mimosaceae), *Caesalpinia* (Caesalpiniaceae), *Hibiscus* (*Malvaceae*), *Rubus* and *Oxyanthus* (*Rubiaceae*), *Vitis* (*Vitaceae)* and *Ligustrum* (*Oleaceae*), but these associations are all considered to reflect only casual feeding by adults. In Africa, the only species outside of the genus *Coffea* in which immature stages have been found is *Dialium lacourtianum* (Caesalpiniaceae). The same author in addition described that, borer can attack other species belonging to the genera *Camphor*, *Dendrobium*, *Bombax*, *Swietenia*, and *Leucaena*, *Tectona* (Le Pelley, 1973).

According to the suggestion of Damon (2000), an important factor in coffee producing areas where production is seasonal; the elimination of these alternative hosts, which may support carry-over populations of the pest between the coffee harvest and new crop, could contribute towards a reduction of infestation by *H. hampei*.

2.4.5 Factors encouraging coffee berry borer infestation

The population dynamics of, and the infestation pattern by *H. hampei* are strongly related to dry matter of berry, altitude and climatic factors such as temperature, precipitation and relative humidity (Jaramillo *et al.* 2009a). According to the author, average daily temperatures greater than 26°C (the average daily temperature per year ranged between 17.3–22.3°C for Ethiopia, 18.7–24.5°C for Kenya, 22.3–29.8°C for Tanzania and for Colombia 15.5–29.3°C) could lead to a reduction of the maximum intrinsic rate of increase and consequently, reduced *H. hampei* activity in coffee plantations. The same authors explained that, every 1°C increase in temperature would also increase the actual *rate* towards the maximum value by an average of 8.5%. Since population growth of *H. hampei* is exponentially related to temperature. Thus, areas with higher seasonal temperature close to the optimum development of *H. hampei* would experience high pest pressure as indicated by the higher number of generations of the pest during its active period of the year. Similarly, Westly (2010) described that not only did the female beetles lay more eggs at higher temperatures, but they also drilled deeper into coffee berries, causing more physical damage, and also higher temperatures also caused the female beetles to travel from berry to berry earlier. In addition, Jaramillo *et al.* (2009a) reported that none of the *H. hampei* life stages developed successfully at 15 and 35^{o}C while the youngest life stages (egg and Larvae) developed between 20–33 ^{o}C, whereas second instar larvae, pre-pupa, pupa and adult developed only between 20–30 ^{o}C, also the developmental time influenced by temperature (significantly longer at 20 ^{o}C than at 23, 25, 27 and 30 ^{o}C). The emergence of the searching females from the berries is triggered by high temperature and relative humidity (Baker *et al.*, 1992).

According to the review of Damon (2000), humidity is frequently mentioned as a key factor determining infestation levels and it is a generally held view that *H. hampei* survives for longer and reproduces better in humid, shady conditions. Similarly Wrigley (1988) reported that CBB attacks are more severe where the coffee grown under heavy shade or closely planted and unpruned. According to the same authors, a single very large, dense shade tree can cause a serious local infestation, and the fruit of wild coffee growing in the dense forest are frequently heavy infestation. However, Baker *et al*. (1989) reported that in their study conducted in Mexico, there was no significant difference between different level of shade and infestation levels. Again this idea was reflected by Soto-Pinto (2002) and it is described as the total sunlight and shade cover did not have a significant effect on the incidence of coffee berry borer. Also the third idea reviewed by Munoz *et al*. (1987) and Ticheler (1961) as cited by Damon (2000), indicate that higher *H. hampei* infestation levels in medium shade than in full sun or heavy shade and that the pest attacked both shaded and full-sun plantations equally. The pest and its brood are protected from humidity fluctuations inside the maturing berry, but ambient humidity can become critical during the inter harvest period when coffee berries become black and dry. Conversely, excessive humidity during the post-harvest period may cause accelerated rotting of coffee berries on the ground, reducing the food supply.

According to the review of Waterhouse (1998), at higher elevations development is somewhat prolonged and *H. hampei* has a low pest status in highland coffee growing areas in East Africa. Also, Wrigley (1988) indicated that the lower the altitude the more severe the damage caused by CBB. On the other hand, the differences in cropping systems and farming practices may therefore create variations in field conditions that may favor or disfavor multiplication of *H. hampei* (Kucel *et al*., 2009). As a result, the management practices indicated positive effects on CBB infestation levels. The percentage CBB infestation decreased with increase in management levels while percentage CBB mortality increased with increase in coffee management levels (Mugo, 2008). Furthermore, dry matter content of the endosperm is the most crucial factor determining the attack by *H. hampei* and its speed of penetration into the coffee berry. Seeds with less than 20% dry matter content are either abandoned after an initial attack, or the female waits in a tunnel bored into the exocarp until the endosperm has accumulated the sufficient amount of dry matter content for the development of her offspring (Alonzo, 1984 as cited by Jaramillo, 2010)

2.4.6 Coffee berry borer management methods

2.4.6.1 Natural enemies and Biological control

Many natural enemies of the coffee berry borer have been reported, including nematod, predators (e.g. ants), fungal entomopathogens (e.g. *Beauveria bassiana and Metarhizium anisopliae)* and parasitic wasps (e.g. *Cephalonomia stephanoderis*, *Heterospilus coffeicola*, *Phymastichus coffea* and *Prorops nasuta*) (Wrigley, 1988; Waterhouse, 1998; CABI, 2006).

According to the review of Waterhouse (1998), the *B. bassiana* has been observed attacking *H. hampei* in Brazil, Jamaica, Cameroon, Congo, India and other many countries. As per the opinion of the reviewer, the new Caledonian strain is particularly virulent strain and can cause death of *H. hampei* in five days, moist warm condition favor the incidence of this pathogen. In spite of such advantage of *B. bassiana*, Baker (2000) reported that applications of the fungus in the field tend to be variable, high mortality of the borer have been achieved only at uneconomically high doses. At lower doses, the mortality is usually between 20 and 50% of adult females entering the berry. According to the report of Rosa *et al.* (2000), *B. bassiana* was more virulent to CBB than *M. anisopliae*. In Indonesia, *B. bassiana* was used in integrated pest management (IPM) in combination with cultural practices and application of pesticides (Wiryadiputra *et al*., 2008).

Entomopathogenic nematodes are important biological control agents of *H. hampei* which can cause high mortality of both adult and larva in coffee berries left after harvest, especially those found on the ground. Spraying of nematodes on fallen berries might remove the need to collect them (Allard and Moor, 1989).

Species of bethylid wasps are larva and pupa ecto-parasitoids of *H. hampei* (Chapman, 2008). *Cephalonomia stephanoderis* is a small black bethylid wasp which is native to West Africa (Ivory Cost, Togo). The females, which are 1.6 to 2.0 mm in length, enter bored coffee berries and deposit their eggs on the ventral surface of final stage larvae and pre-pupae of *H. hampei.* The larvae feed as ecto-parasites, exhausting the tissue of the host in 4 to 6 days, and then spinning a silken cocoon in which to pupate (Waterhouse, 1998). According to the same report, the pupation lasts in 15 days, and the fertilization takes place in the berry where the wasps emerge and the males, fully winged, remain there after the females have left. *Cephalonomia stephanoderis* can cause parasitism rates approaching 50%, and the parasitoid can be mass reared using coffee berry borer-infested coffee berry and has been imported to more than 20 countries (Ticheler, 1961 and Klein-Koch *et al.*, 1988 as cited Vega *et al.*, 2009).

The first coffee berry borer parasitoid reported was the bethylid, *Prorops nasua.* It is native to Uganda, Kenya, Tanzania, Cameroon and Congo, and can be found throughout most coffee producing countries in Africa (Le Pelley, 1968; Waterhouse, 1998). Wrigley (1988) described that, *P. nasuta* is a dark brown bethylid wasp about 2.3 mm in length, acts both as a parasite and a predator, the adult parasite feeding on eggs and young larvae, while the larvae attack the fully grown larvae and pupae of the borer. Consequently, this parasite is most numerous in over ripe berries. According to Waterhouse (1998), the life cycle of *P. nasuta* from egg to adult lasts within 17 to 33 days (average 29 days), also on coffee the fertilized females enters an infested berry via the bore hole of the adult *H. hampei,* choosing berries on trees rather than those on the ground. In contrast, Jaramillo *et al.* (2009b) showed that 97% of the *P. nasuta* collected in the field originated from berries collected on the ground. As the review of Le Pelley (1968) and Abraham *et al*. (1990), the females of *P. nasuta* consume several eggs and unparasitized larvae per day and they will also eat pupae, normally all stages of the beetle in a berry are killed either by parasitization or predation before the female leaves.

According to the study done by Chiu-Alvarado *et al.* (2009) have shown that, *P. nasuta* is attracted to coffee berry borer-infested coffee berries, as well as to larvae/pupae and frass removed from the infected berries, but not to uninfected berries, or to larvae/pupae and frass obtained from artificial diets, which indicate that an unidentified attractant produced by the interaction between the insect and the berry is critical for *P. nasuta* to locate its host. This species able to maintain high population in the field, if there are multiple release through the coffee bearing season, otherwise, parasitoid population decreased remarkably (Infante *et al.*, 2005).

The braconid *Heteropilus coffeicola* was discovered by Haergreaves in Uganda, and is believed to be distributed throughout coffee producing countries in Africa (Le Pelley, 1968; Wrigley, 1988). *Heteropilus coffeicola* is about 2.5 mm long with antennae with the same length. The adult does not live in the berry but flies about ovipositing on the egg of borer through the hole in the berry, only single small egg is laid in each berry, and the larva that emerge after about six days feeds on beetle eggs and larva over a period of 18 to 20 days, consuming 10 to 15 eggs and larvae per day (Wrigley, 1988; Waterhouse, 1998). According to the review of Vega *et al.* (2009), a rearing technique for this parasitoid has not yet been developed, that makes it difficult to import the parasitoid to other countries for field release.

Phymastichus coffea parasitoid first recorded in Togo as recently as 1989 (Borbon-Martinez, 1989 as cited by Waterhouse, 1998), causing up to 30% parasitization, but is now known also from Ivory Cost and Kenya. In Mexico resulted high level of parasitism that was reported up to 55% (Vega *et al.*, 2009). According to the review of Jaramillo *et al.* (2006), it is endo-parasitoid of adult female and can parasitize *H. hampei* females within hours of emerging once parasitized, female *H. hampei* cease oviposition and usually die after 12 days. Additionally, the highest level of parasitism were recorded in berries less than 160 days old, before female *H. hampei* reached the endosperm of the berry, thus preventing damage to the coffee bean. Similarly, as (CABI, 2011) report, *Phymastichus coffea* was seen as a very important bio-control agent because it attacks adults and thus might help to prevent establishment of the borer in the endosperm, where economic damage is caused. It can also parasitize borers from more than one berry. According to the findings of Espinoza (2009), indicate that *P. coffea* is a promising biological control agent against the CBB, perhaps not as a single method of control, but as an important component of a pest management program. On the other hand, to enhance a biological control agents against coffee berry borer, some research like, testing ant predation on the coffee berry borer (Armbrecht and Gallego, 2007), parasitism of the *H. hampei* by *Trichogramma pretiosum* (Lopez-Meza *et al.*, 2003) and *Bacillus thuringlensis serovar isrealensis*, that are highly toxic to coffee berry borer (Mendez-Lopez *et al.* 2003) were conducted and promising results were observed to control the beetle.

In Ethiopia, According to the review of Millon (1998) as cited by Damon (2000) described that, *H. hampei* was found in the south and south-east of Ethiopia associated with three unidentified parasitoids, two attacking the larval stage and one the adult stage. But, very recently, the research conducted by Chemeda *et al.* (2011) reported the presence of *Prorops nasuta* in Berhane-Kontir and Yayu forest coffee populations (FCPs) attacking *H. hampei* at larval stage.

2.4.6.2 Cultural management method

According to the report of many authors, like Le Pelley (1968); Waterhouse (1998); CABI (2006); Aristizabal (2011), maintain/keeping the plantation sanitation is an old-established tradition in pest control, and the coffee berry borer has long been tackled by such practices. They describe that, the coffee berry borer in favorable conditions of climate and when coffee berries are present throughout the year can maintain an uninterrupted series of generations, at least eight separate but overlapping generations being possible in a year. Though, one of the most important control and management practice is the punctual, complete harvest and rigorous collection of remnant berries from the tree and the ground. Similarly, Aristizabal (2011) reported that the efficient manual removal of all mature and dry (ripe and over ripe) berries which serve as sources for new infestations help to break the life cycle of the coffee berry borer.

Similarly, according Saldarriaga (1994) and Bustillo *et al.* (1998) cited by Aristizabal (2011), labor intensive, regular harvesting and sanitation of mature berries removes developing CBB before they emerge to start another life-cycle. The same authors reported that, a sanitation picking reduced CBB infestation of berries from 70% to less that 6%. However, the effectiveness of regularly harvesting mature berries to control CBB depends on how efficiently they are removed. It estimated that at low to moderate CBB densities, the manual removal of mature berries is a highly effective strategy when less than 5 such berries per coffee tree remain after one pass of harvesting, reasonably effective when 6-10 berries remain, and ineffective when more than 10 such berries are left on coffee trees. In line with above idea, CABI (2011) indicated that harvesting berries by itself an important control measure which reduce infestation as it breaks the cycle and leaves little substrate for immigrating coffee berry borers. It was also suggested that collected berries should be boiled or buried if infestation levels are high (CABI, 2011).

Baker and Barrera (1992), Anna-Elisabeth (2005) and Hawaii Department of Agriculture (2010) suggested the following recommendations to control of CBB: a) reduce heavy shade b) prune coffee to keep it as open as possible to create a less humid environment for the beetle. c) picking should take place at least once a week in the main harvest season and once a month at other times to prevent over-ripe infested cherries falling to the ground where adult females can survive and attack out of season cherries. d) Cherries left on the ground should be as little as possible. Dropped cherries will provide a source of beetles to re-infest the next crop. e) Before a main flowering the crop should be stripped completely F) All infested cherries should be destroyed by burning, deep burying or if possible rapid sun drying.

2.4.6.3 Chemical control

According to the report of CABI (2006), due to the toxicity of many insecticides i.e. effects on the environment adverse and natural enemies of CBB, careful consideration should be given to their use. On the other hand, chemical application is difficult and less effective for the reason that CBB spends much of its life protected within the coffee berry and eggs are laid within the berry. Then, if pesticide application is necessary, pesticide should be applied before the insect bores into the berry or only when the adult female leaves the berry, typically at the end of the inter-harvest period to find and colonize a fresh berry, that the insect is exposed to contact chemical control (Anna-Elisabeth, 2005).

Endosulfan, chlopyrifos, fenintrothion, fenthion and pirimiphos are the some of the common chemicals used to control CBB (Mugo and Kimemia, 2009; Damon, 2000; Anna-Elisabeth, 2005). Among those synthetic chemicals endosulfan is commonly used and most effective in coffee farms to manage CBB in many part of the world. However, the toxicity of enosulfan has contradictory research outputs, the first result indicated the less toxicity nature of endosulfan and its harmlessness to the three common parasitoids namely *Cephalonomia stephanoderis*, and *Phymastichus coffea* and *Prorops nasuta*, But, a study conducted in Colombia showed that the parasitoids were killed by application of endosulfan (Decazy, 1991 and Guzman, 1996 as cited by Damon, 2000 respectively). In addition to this, its frequent use has led to the development of resistance of *H. hampi* against this insecticide in New Calendonia (Brun *et al.*, 1989).

If insecticides are used, it is advisable to use those that should not destroy natural enemies of CBB or other useful organisms and has less risk to environment. Consequently, insecticides are only advised when the pest is out of control and cultural measures have failed (Wrigley, 1988), and it would be a great advantage to have the support of additional control measures (Waterhouse, 1998).

2.4.6.4 Integrated pest management

In an integrated pest management system, CBB monitoring, identification, and setting economic injury level (EIL) are the main components for managing the beetle. When qualitative and quantitative losses caused by the pest were considered together, the EIL was 4.3% of bored berries for both conventional and organic coffee (Fernandes *et al.*, 2011).

Using traps is relatively new method of CBB control, and the Brocap trap is a trap specially designed for *H. hampei* control. In El Salvador and in Indonesia trap is considered as a useful component of IPM for CBB control (Wiryadiputra, 2008). In Tanzania, extracts from Neem and Tephrosia are used to control the CBB with encouraging results (Magina, 2005). According to Mugo and Kimemia (2009) for effective management of CBB a combination of various pest management strategies which are economically feasible, sustainable and environmentally friendly are advocated. Therefore IPM of CBB which consists of bio-control, botanicals, cultural methods and selective insecticides in a compatible way contributes for sustainable management of CBB.

3. MATERIALS AND METHODS

3.1 Description of the study area

Assessment of coffee berry borer infestation was conducted in Yeki and Mengeshu woredas, which are located in southwestern part of Ethiopia under the political administration of both Southern Nations Nationalities and Peoples Regional State (SNNPRS) and Gambela Regional State. Both woredas are among the major coffee producing areas of the country.

Baya kebele is found in Yeki woreda, Sheka Zone in SNNPRS, which is located 595 Km southwest of Addis Ababa, at 07^o 08.6" N latitude and 35^o 22.2" E Longitude, and with elevation of 1110m.a.s.l. The average annual rainfall is 1060.3mm with mean minimum and maximum temperatures of 15.9^{o}C and 31.82^{o}C (average 23.9^{o}C), respectively (Secondary data from Yeki woreda agricultural office, unpublished)

Shone and Anderacha kebeles are found in Mengeshu woreda, Mejenger zone in Gambela Regional State, and are located 647 Km far from Addis Ababa in the same direction to Yeki woreda, in south western part of the country. The Shone kebele is geographically situated at 07^0 24.2'N latitude and 35^o 21.9" E Longitude and at an elevation of 1400m.a.s.l. Anderacha kebele is also located at 07^0 24.8'N latitude and 35^o 21.9" E Longitude and at an elevation of 1720m.a.s.l. The mean minimum and maximum temperatures are 17^{o}C and 32^{o}C respectively, and with an average annual rainfall of 1500mm (secondary data from Mejenger zone Agricultural office, unpublished).

3.2 Field assessment of coffee berry borer

3.2.1 Experimental material (coffee variety)

In order to determine damage caused by CBB, the study was carried out on Arabica coffee (*Cofea arabica* L.) cultivar 744, which has been widely planted and adapted in the area since 1991 with the establishment of coffee state farms in both Yeki and Mengeshu (Kabo) woredas. Variety 744 is cultivated under a wide range of elevation. It was used for assessment of berry borer incidence both in garden and plantation coffee stands in the field at different berry development stages (red ripe, dry over ripe, dry left over and fallen berry) in the field.

During the damage assessment materials such as hand lens, sensitive balance, scalpel blade, plastic bags and other materials were used.

3.2.2 Experimental procedure and design

The field assessment on coffee berry borer damage was conducted at three different sites located at different elevations Baya (1110m.a.s.l), Shone (1400m.a.s.l.) and Anderacha (1720m.a.s.l.) which were purposely selected by considering the representativeness of major coffee producing areas of both woredas. In each location coffee farms under two different management systems (garden and plantation coffee) were selected in three replications to come up with six coffee farms for each location. Therefore, totally 18 coffee farms were selected from the three sites for the damage assessment. At each selected coffee farm, 30 coffee trees were selected by employing systematic sampling method in a zigzag pattern. Then, each selected tree was tagged to collect data in four rounds at different coffee berry development stages (red ripe, dry over ripe, fallen berry, dry left over stage berry). Based on Esayas (2004) and Mugo (2008) description, 10 berries were randomly collected from each tree (i.e. totally 300 berries per site) in each replication for the assessment of damage percentage and, 100 damaged berries were randomly selected for data collection of number of holes per bean, weight loss %, CBB development stage, and damaged bean color.

3.2.3 Experimental treatments

In both woredas, coffee was grown in the elevation range of 1050 to 1900 m above sea level. However, the majority of coffee is produced within the altitude range of 1100 to 1750m.a.s.l. (secondary data from Yeki woreda and Mejenger zone Agricultural office, unpublished). Based on this data, level of CBB infestation (damage) was assessment at the three sites selected from lower, middle and upper altitudes in the area. The lower location, Baya (1110m.a.s.l.) was selected from Yeki woreda, while the middle, Shone (1400m.a.s.l.) and the upper Anderacha (1720m.a.s.l.) sites were selected from Mengeshu woreda. From each location, each three plantation and garden farms were selected for the assessment. The damage assessment at different coffee development stages (red ripe, dried over ripe, fallen berries and dried leftover berries) was carried out at all the selected locations and under the two management systems.

3.2.4 Data collected

3.2.4.1. Percentage of damaged berries

To study the level of damage caused by CBB, 300 berries were collected from randomly selected 30 coffee trees for the different fruit development stages. All the collected berries were carefully examined for the presence of borer attack by observing the presence of CBB entry holes. Percentage damaged berries by CBB was calculated for each fruit development stage using the following formula.

$$\text{Percentage damaged berries} = \frac{DB}{TB} \times 100$$

Where: DB = Damaged berries
TB = Total collected berries

3.2.4.2. Number and developmental stage of coffee berry borers

Among fruits of each selected stage of berry development collected from the selected locations and both management systems, 50 damaged berries were carefully dissected by scalpel blade and the number of coffee berry borers at different growth stages (egg, larva, pupa and adult) was recorded.

3.2.4.3. Weight loss of coffee berries

Berries were separated in to damaged and undamaged (healthy) to take 100 seed weight. Therefore, 100 berries from each category were weighed separately using a sensitive balance (SPB 03, Germany) and percentage weight loss of damaged coffee berries was calculated the method recommended by Adams and Schulten (1978).

$$\%\ \text{weight Loss} = \frac{Wu - Wd}{Wu} \times 100$$

Where:

Wu= Weight of undamaged berries

Wd= Weight of damaged berries

3.2.4.4. Number of holes per bean

For all combinations of location, management system and stage of berry development, 50 berries were dissected and the number of holes per bean was counted to calculate the values as mean number of holes per coffee bean.

3.2.4.5. Proportion of discolored damaged beans

This data was taken from randomly picked 50 damaged sample beans through subjective assessment of the damaged and discolored beans. The data was calculated by dividing the specific number of damage and discolored beans to the total number of examined damaged sample beans and multiplied by hundred.

$$\%DDB = \frac{NDB}{TNDB} X100$$

Where: %DDB= percentage of damaged and discolored beans
NDB = number of discolored beans
TNDB= Total number of damaged bean

3.3. Survey of perception, knowledge and management practices of coffee berry borer

Three peasant associations, ten kebele agricultural stations and three coffee farms of Teppi coffee plantation enterprise were purposively selected to randomly select respondent farmers, development agents and experts in Teppi coffee plantation enterprise respectively. The main reasons for the selection of these areas were because they are the most important coffee growing areas nearby the field study sites. Accordingly, the perception, knowledge and management practices of farmers', development agent's (DA) and coffee plantation enterprise expert's about coffee berry borer were assessed based on questionnaires prepared and provided to 200 farmers (66, 67 and 67 farmers from each peasant associations), 30 development agents (3 DAs from each agricultural stations) and 24 coffee plantation enterprise experts (6 experts from each coffee farm). Farmers and Teppi coffee plantation enterprise expert Respondents were selected based on simple random sampling methods.

Data pertaining to the perception, knowledge and management practices of farmers, development agents and coffee plantation enterprise experts with reference to coffee berry borer were collected using a structured questionnaire prepared for each of them. In addition, focus group discussion with respondents and visual observations of coffee management systems were made in each of the survey area.

3.4 Data analysis

Data pertaining to percentage damaged berries by CBB, average number of holes per bean, percentage weight loss, number and developmental stages of CBB, and percentage of damaged and discolored beans were analyzed using SAS computer software version 9.2 (SAS Institute, 2008).

Arc sine transformation was employed for percentage of damaged berries. Similarly, square root transformation $(X+0.5)^{1/2}$ was carried out for data on weight loss, number holes, and number and stage of CBB before analysis of variance was made (Gomez and Gomez, 1984). Data were subjected to the three factorial randomized complete block design (RCBD) in three replication analysis of variance (ANOVA) using SAS computer software version 9.2 (SAS Institute, 2008). Whenever the treatment was significant, least significant difference (LSD) was used for mean separation at p=0.05. Pearson correlation was applied for the response parameters. Also SPSS, version 16 statistics software program was used for questionnaire response data processing (SPSS, 2006).

4. RESULTS AND DISCUSSION

Part I: Field assessment

4.1 Assessment of coffee berry borer

4.1.1 Level of berry damage by coffee berry borer

In the present study, coffee berry borer damage was observed at the three locations (Baya, Shone and Anderacha) and for different berry development stages (red ripe, dried over ripe, fallen berry and dried leftover). The effect of different locations and different berry development stages on the percent damage by CBB was found to be highly significant ($P<0.0001$). The interaction between location and berry development stage was also highly significant ($p<0.0001$), while the interaction between location and management system did not show a significant variation ($p>0.05$) for percent damage due to CBB (Appendix Table 1).

The interaction indicated the highest mean damage percentage, 37.50% (ranges from 32.00 to 43.00%) of CBB at Baya in dried leftover berries, followed by 19.30% (ranges from 14.00 to 23.33%) at Shone for the same berries and 13.33% (ranges from 10.00 to 16.67%) at Baya in dried over ripe cherries. On the other hand, the lowest mean damage percentage, 0.50% (ranges from 0.00 to 1.00%) of CBB was observed at Shone on red ripe cherries followed by 1.21% (ranges from 0.60 to 1.67%) at Baya for red ripe cherries. But, no damage was observed on red ripe cherries at Anderacha (Table 1).

Results of the current study indicate that the incidence of CBB damage increased with a decrease in elevation. Hence lower altitudes, such as Baya, are highly favorable to CBB infestation to cause damage on coffee berry than other locations. This finding also it confirms the presence of CBB damage in areas as high as 1720m.a.s.l. on dried over ripe, fallen and dried leftover cherries. In agreement with this study, in Ethiopia, Esayas *et al.* (2003, 2004 and 2005) reported the presence of CBB under a wide range of altitudes from 1200m.a.s.l. at Teppi to 1900m.a.s.l. at Gera, with the level of infestation being very low in the later. The reports also indicated that altitude is among other factors, which appeared to limit the distribution of the borer and shows a significant negative correlation with infestation level. In addition, mean berry borer infestation in the survey area was 8-60%. Similarly, EARO (2000) described the presence of CBB infestation in some coffee growing areas of Ethiopia with mean percentage of 13.3-61% infestation on dry coffee berries. On the other hand, Chemeda *et al.* (2011) have reported that low incidence of CBB, *i.e.* 8.38 and 4.98 % on dried leftover and fallen berries, respectively. The authors also reported negative relationship between CBB incidence and altitude.

Table 1: Interaction effect of location and berry development stage on mean damage (%) of fruits by coffee berry borer

Location	Berry Development Stages			
	Red ripe	Dried over ripe	Fallen	Dried leftover
Baya	1.21(6.20)^{h}	13.33(21.32)^{c}	9.56 (17.90)^{d}	37.50 (37.73)^{a}
Shone	0.50 (2.77)^{i}	8.05 (16.32)^{e}	6.11 (14.13)^{f}	19.30 (25.99)^{b}
Anderacha	0.00 (0.33)^{j}	2.00 (7.89)^{g}	1.39 (6.45)^{gh}	6.89 (14.95)^{ef}
LSD $_{(0.05)}$	1.556			
CV $_{(\%)}$	6.10			

Values in parentheses show the transformed data (arc sine transformation) and means followed by the same letter (s) are not significantly different (p=0.05)

In Kenya, the occurrence of CBB on Arabica coffee has been observed at altitudes up to 1880m.a.s.l. with 1650m.a.s.l. being more conducive for the pests (Mugo, 2008). In other studies CBB damage was reported to reach 80% in Uganda, 84-96% in Congo, 60-80% in Brazil (Le Pelley, 1968; Waterhouse, 1998) and 33.70% in Jamaica (Reid, 1983).

As indicated in Table 1, less CBB damage percentage was observed on red ripe cherries. In agrement with this earlier studies indicated 1.40% of CBB damage on red ripe cherries (Esayas *et al.*, 2003). In the present study, however, the overall mean of damage on red ripe at Baya reduced to 1.21%, but the damage of CBB on red ripe cherries at Baya in plantation coffee was about 1.67%, which is slightly higher than eariler studies. On the other hand, various authors such as Le Pelley (1968); Damon (2000); Anna- Elisabeth (2005) and CABI (2006) have reported that CBB attacks all developmental stages of coffee berries, causing a considerable amount of losses in most countries where it is prevalent.

Among the different coffee development stages, from highest mean damage of 21.23% (ranges from 3.33 to 43.00%), the highest damage (43.00%) was recorded for dried leftover cherries at Baya under plantation farms. This highest damage in leftover cherries particularly at Baya in coffee plantations could be related with favorable environmental conditions of the location and availability of unpicked dry leftover cherries, which serve as source of infestation for a new coming CBB. In Ethiopia, as reported by Chemeda *et al.* (2011), the mean incidence can reach 8.38% on dried leftover berries in forest coffee, and Esayas *et al.* (2003) have indicated that mean percentage damage ranged from 25 to 95% on dried leftover coffee in Jimma area.

Dried over ripe cherries showed higher damage of CBB next to dried leftover berries. Percentage damage on fallen coffee berries was lower than on those dried over ripe berries. This implies low probability of attack in fallen berries on ground, which may be due to moist condition of the ground in the study area that facilitated decomposition of the pulp of fallen berries, thus unfavorable condition for feeding and reproduction of CBB.

The high incidence (damage) observed on dried over ripe berries (10.00% to 16.67%) needs a great attention, because such huge amount of damage can cause direct loss in yield and quality of harvestable products. It also indicates the importance of early harvesting at red ripe stage in order to minimize the occurrences of CBB and helps to increase the quality of coffee.

The findings of the present study revealed that the interaction between management system and different coffee berry development stages was highly significant ($P<0.0001$) for damage percentage of CBB (Appendix Table 1). The results indicate maximum damage percentage 24.51 (ranges from 8.67 to 43.00%) under large large-scale management system on dried leftover cherries, followed by 17.95% (ranges from 3.33 to 34.00%) in garden coffee stands for the same berry development stage, while minimum damage percentage of 0.43 (ranges from 0.00 to 1.30%) was observed in garden coffee on red ripe coffee cherries, followed by 0.70% (ranges from 0.00 to 1.67%) for plantation coffee management system on red ripe cherries (Table 2).

In this study, the interaction of different fruit coffee development stages and coffee management systems indicates that the mean percent berry damage was consistently higher for all berry development stage under plantation coffee management system than in garden coffee stands. Dry leftover coffee cherries showed the highest damage percentage in plantation coffee, while red ripe cherries had the lowest value in garden coffee management system. These results clearly indicate higher level of infestation in large scale plantations than in small holdings of garden coffee. It also shows that management practices which include harvesting time, harvesting frequency and harvest types play a great role in reducing the incidence of CBB.

In large scale coffee plantations about 10-30% of coffee field is not timely harvested, thus leftover on the tree and fallen on the ground due to shortage of labor (data obtained from survey result). Such leftover berries are used as sources of infestation of CBB to the next production season. On the other hand, in the garden coffee, most probably in relation to the raising coffee prices for the last four to five years, the yield is timely harvested at red ripe stage, hence dried leftover and fallen berries are estimated to be less than 5% (personal observation). This condition might have contributed to the reduced incidence of CBB in garden coffee stands. In large scale coffee plantations the size of farms also contributes to the poor management practices and indirectly to increased level of infestation of CBB. In agreement to the results of the present study, Esayas *et al.* (2004) have also indicated the presence of high level of infestation of CBB in most of large scale coffee plantations and in research centers than in small scale farmer holdings. Similarly, Mugo and Kimemia (2009) have reported that percentage CBB infestation decreased with increased management level, while CBB mortality increased with increase in coffee management level. Furthermore, Aristizable (2011) suggested harvesting of leftover berries as well as efficient manual removal of all mature and dry cherries which serve as a source for new infestation. Likewise, CABI (2011) indicated proper harvesting practice as an important control measure of CBB.

Table 2: Interaction effect of production system and berry development stage on mean damage percentage of coffee berry borer

Berry Development stage	Coffee Management System	
	Plantation	Garden
Red ripe	0.70 (3.30)^{g}	0.43(2.90)^{g}
Dried over ripe	9.70 (17.32)^{c}	5.89 (13.03)^{e}
Fallen berry	7.22 (14.87)^{d}	4.15 (10.79)^{f}
Dried leftover	24.51 (28.76)^{a}	17.95 (23.68)^{b}
LSD $_{(0.05)}$	1.556	
CV $_{(\%)}$	6.1	

Values in parentheses show the transformed data (arc sine transformation) and means followed same letter (s) are not significantly different at p=0.05

As indicated in Table 2, high incidence on leftover berries in large scale coffee plantations not only contributed to infestation with CBB for that specific farm, but might have also facilitated high level of increment of infestation in nearby garden and semi-forest coffee stands, because of the ability of adult female beetles to fly from one farm to another. In line with this, Wrigley (1988) has indicated that when food becomes scarce, female CBB leave the fruits in which they have developed, and fly to neighboring trees. In general, in any coffee management system, regular and effective picking of coffee cherries and removing leftover fruits from the tree and fallen berries from the ground is important practice to break the life cycle and to reduce the infestation level of CBB.

4.1.2 Number of holes bored per coffee bean

In the present study, location, berry development stage and the interaction between the two showed highly significant effect on number of holes bored into coffee beans (P< 0.0001). But the effect of coffee production system and its interaction with other treatments did not show significant differences for the number of holes per bean (p>0.05) (Appendix Table 1)

It was observed that the highest mean number of (10.88) holes (ranges from 8.40 to 13.10) into beans was recorded at Baya on dried leftover cherries, while the lowest mean value (0.83) holes (ranges from 0.00 to 1.00) was found at Shone on red ripe cherries. But, no damage was recorded at Anderacha (1720m.a.s.l.) on red ripe cherries (Table 3).

Table 3: Interactions effect of location and berry development stage on mean number of holes per damaged coffee beans

Location	Berry development stage			
	Red ripe	Dried over ripe	Fallen	Dried leftover
Baya	1.02 (1.23)^{gh}	3.88 (2.09)^{c}	3.28 (1.94)^{cd}	10.88 (3.37)^{a}
Shone	0.83 (1.14)^{h}	3.01 (1.87)^{d}	2.16 (1.63)^{e}	6.46 (2.64)^{b}
Anderacha	0.00 (0.71)^{i}	1.52 (1.42)^{fg}	1.26 (1.33)^{gh}	2.13 (1.62)^{ef}
LSD $_{(0.05)}$	0.2007			
CV $_{(\%)}$	6.46			

Values in parentheses represent the transformed data $(x+0.5)^{1/2}$ and means followed by same letter (s) are not significantly different at $p \geq 0.05$

This could probably be because the condition at Baya provided the pest with favorable environmental conditions for early and wide infestation of the coffee cherries beetles. Similarly, dried leftover cherries at Baya showed the highest number of holes bored by CBB. The high level of infestation (damage) of berries was the main cause of high number of holes into beans, as more than one borer might have infested a single berry. The increase in number of holes markably contributed to weight losses and quality deterioration of coffee beans. On the contrary, red ripe cherries at all elevations showed less number of holes per bean. Similarly, Esayas *et al.* (2003) have reported that the highest numbers of perforations per damaged berries with mean values of 2.6 were observed for dry coffee cherries. In addition, Esayas *et al.* (2005) have also indicated the presence of one to six entrance holes per damaged berry.

Plate 1: Perforations of beans damaged by coffee berry borer

In most of red ripe berries only one hole per damaged bean was observed, while in dried leftover cherries on average up to 13.10 holes per damaged bean were observed. These high number of holes observed at different development stages (except red ripe stage) or numerous perforation of beans (Plate 1) not only contribute to the reduction of yield or weight losses, but also lead to the total damage of beans and loss of price. If the holes into bean are more than two, it is considered as severe insect damage and categorized as primary defect of coffee during raw quality evaluation (Kosalos *et al.*, 2004; ECX, 2011). As it was mentioned earlier (section 4.1), the high number of holes that contribute to reduction of yield and quality on harvestable crop (red ripe and dried over ripe berries) needs a great attention. In line with this Reid and Mansingh (1985) have indicated that the presence of perforation of the fruit is a reliable indication of bean damage by CBB. Similarly Reid (1983), Le Pelley (1968), Vega *et al.* (2009) and Vega *et al.* (2011) have reported that boring of a hole in the coffee berry start during the egg laying of adult female beetle in internal galleries, with hatched larvae feeding on the endosperm. Feeding into beans (damage) reduces yields (sometimes loss in overall yield), lowers quality of the seed and can result in the abscission of the berry. According to Crowe (2004), heavily damaged beans by *H. hampei* when roasted, the beans are distinctly darker in color than normal beans and showed significant off-flavors with predominantly bitter and tarry nature and caused total loss of aroma, flavor and acidity, which generally create high to very high negative effect on cup quality.

4.1.3 Weight loss (%) of coffee berries

In the present study, differences between locations, berry development stages, coffee production systems, and due to the interaction between berry development stage and location, and among berry development stage and coffee production system were highly significant (P<0.0001) for weight loss percentage of damaged coffee berries. But, the interaction between location and coffee production system was not significant (Appendix Table 1).

Accordingly, maximum mean percentage of weight loss (8.11%) was observed at Baya for dried leftover cherries, followed by mean loss of 4.01% at Shone for the same berry type, while the minimum value (0.17%) was recorded at Shone on red ripe cherries, followed by the value recorded (0.20%) at Anderacha for fallen cherries. But, no damage and weight loss was recorded on red ripe Cherries at Anderacha (Table 4).

It is obvious that the holes of beetles into beans and feeding inside a bean can cause weight losses of berries. The weight losses of damaged berries increase with the duration infestation, population of borer per damaged berry and favorable environment conditions such as high temperature in areas like Baya. In line with this, Damon (2000) has reported that the boring and feeding activity of adults and progenies cause a reduction in yield and quality of the final product. Wrigley (1988) has also indicated that the adult CBB breeds inside the bean and the larva continues the destruction of one or both seeds in a berry until they are valueless. Similarly, Westly (2010) has described that not only did the female beetles lay more eggs at higher temperatures, but they also drilled deeper into coffee berries, causing more physical damages.

Table 4: Interaction effect of location and coffee berry development stage on mean weight loss (%) of damaged coffee berry

Location	Berry Development Stage			
	Red ripe	Dried over ripe	Fallen	Dried leftover
Baya	0.23 (0.85)^{h}	3.00 (1.87)^{c}	2.02 (1.59)^{d}	8.11 (2.93)^{a}
Shone	0.17 (0.81)^{h}	1.63 (1.46)^{e}	0.97 (1.21)^{f}	4.01 (2.12)^{b}
Anderacha	0.00 (0.71)^{i}	0.45 (0.98)^{g}	0.20 (0.84)^{h}	1.50 (1.41)^{e}
LSD $_{(0.05)}$	0.05483			
CV $_{(\%)}$	2.21			

Values in parentheses are the transformed data $(x+0.5)^{1/2}$ *and means followed by same letter(s) are not significantly different* at $p \geq 0.05$

As shown above, prolonged period after ripening and stay of berries on the tree for relatively longer duration at low elevations lead to high damage and more holes which result in weight losses of coffee berries. Such a weight loss of berries is directly related to reduction of yield and loss of profit to coffee growers. As previously stated, this study suggests that could be early picking of cherries after maturation much more helpful to reduce damage and weight losses. In agreement with this study, Waterhouse (1998) has reported that tunneling by the beetles and their larva brings about progressive degradation, so that coffee bean is reduced to a mass of frass.

CABI (2006) also indicated that attack by CBB can result in premature fall of berries and, hence, total crop loss, but the berries remain attacked until harvest and weight of their bean are reduced to a lower quality and their flavor is adversely affected. In addition, Anna-Elisabeth (2005) reported that damaged berries remain on the tree, but their commercial value decreases due to reduced weight of the beans. On the other hand, the highest mean percentage weight loss of coffee berries (4.86%) (ranges from 1.4 to 8.54%) was observed in at plantation coffee production system for dried leftover cherries, and the lowest value (0.06%) (ranges from 0 to 0.18%) was recorded for garden coffee management system on red ripe cherries (Table 5).

Table 5: Interaction effect of management system and berry development stage on mean weight loss (%) of damaged berry

Berry Development Stage	Management System	
	Plantation	Garden
Red ripe	0.21 (0.84)^{e}	0.06 (0.75)^{f}
Dried over ripe	1.67 (1.43)^{c}	1.72 (1.44)^{c}
Fallen berry	1.10 (1.22)^{d}	1.03 (1.20)^{d}
Dried leftover	4.86 (2.23)^{a}	4.21 (2.08)^{b}
$LSD_{(0.05)}$	0.05483	
$CV_{(\%)}$	2.21	

Values in parentheses are the transformed data $(x+0.5)^{1/2}$ and figures followed by the same letter(s) are not significantly different at $p \geq 0.05$

4.1.4 Number and stage of coffee berry borer

The different developmental stages of CBB (egg, larva, pupa and adult) in damaged berries were observed at all locations of stud and berry development stages with different levels of population. Location and berry development stage showed highly significant difference ($P<0.0001$) for number of eggs, number of larvae and number of adult beetles and significant effect on ($P<0.05$) the number of pupae. Similarly, the interaction between location and berry development stage was significant ($P < 0.05$) for number of larvae and adult beetles. However, coffee production system and its interaction with the other factors was not significant ($P > 0.05$) for all number and stage of development of borer (Appendix Table 1 and 2).

It was observed than mean number of egg was 2.44 (ranges from 0 to 4.5 eggs) at Baya, 1.36 (ranges from 0 to 1.81eggs) at Shone and 0.76 (ranges from 0 to 1.81 eggs) at Anderacha (Figure 1). The mean number of eggs recorded at Anderach was as low as less than of one, which indicates that the effect of location might have created unfavorable environmental conditions to the occurrence and oviposition of adult female borer. But, at Baya relatively high number of eggs was recorded (Figure 1).

In the same way, mean number of pupae recorded at Baya was 0.55 (ranges from 0 to 1.3 pupae) and it was 0.25 (ranges from 0 to 0.8 pupae) at Shone and 0.08 (0 to 0.5) at Anderacha (Figure 2). Mean number of pupa was relatively less compared to other borer developmental stages. Similar to other developmental stages of borer, relatively higher mean number of pupa was observed at Baya (Figure 2).

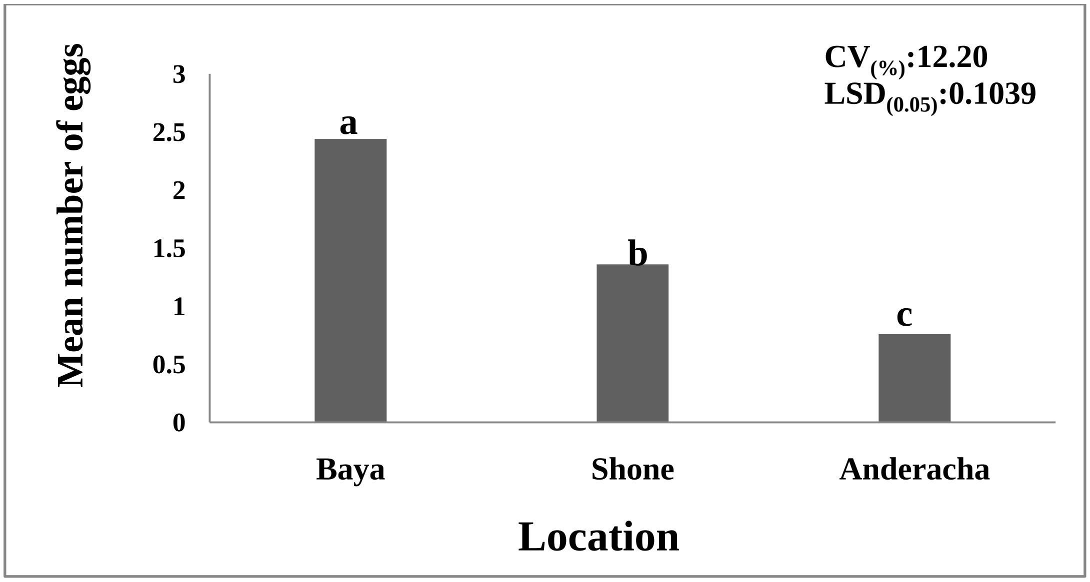

Figure 1: Mean number of eggs of coffee berry borer per damaged berry under different locations.

Figures in parentheses show transformed values and columns or bars capped with same letter(s) are not significantly different at P≥0.05

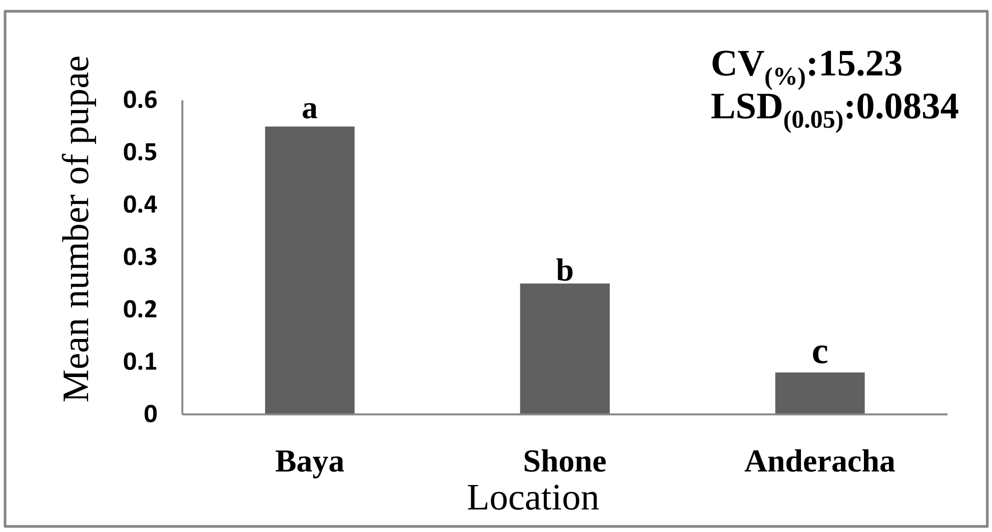

Figure 2: Mean number of pupae of coffee berry borer per damaged berry under different locations

Values in parentheses represent the transformed data $(x+0.5)^{1/2}$ and bars copped with same letter (s) are not significantly different at p=≥0.05

The result of this study showed mean number of 0.28 eggs and 0 or no pupae on red ripe cherries, 1.81 eggs and 0.335 pupae on dried over ripe cherries, 1.37 eggs and 0.34 pupae on fallen berries, and 2.62 eggs and 0.50 pupae on dried leftover berries (Figure 3 and 4). The highest mean number of eggs and pupae of borer was recorded in the dried leftover berries and lowest in red ripe cherries. Mean number of eggs of the borer was also higher in dried over ripe than in fallen berries, but the mean number of pupa was higher in fallen than in dried over ripe cherries (Figure 4).

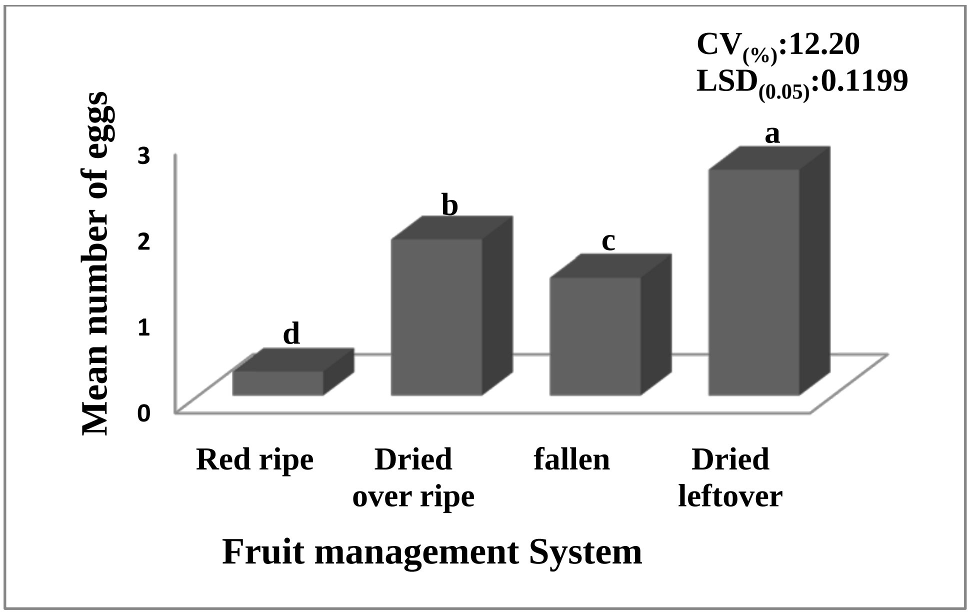

Figure 3: Mean number of eggs of coffee berry borer per damaged berries as influenced by fruit management System

Values in parentheses represent the transformed data $(x+0.5)^{1/2}$ *and columns capped with same letter(s) are not significantly different at p=≥0.05*

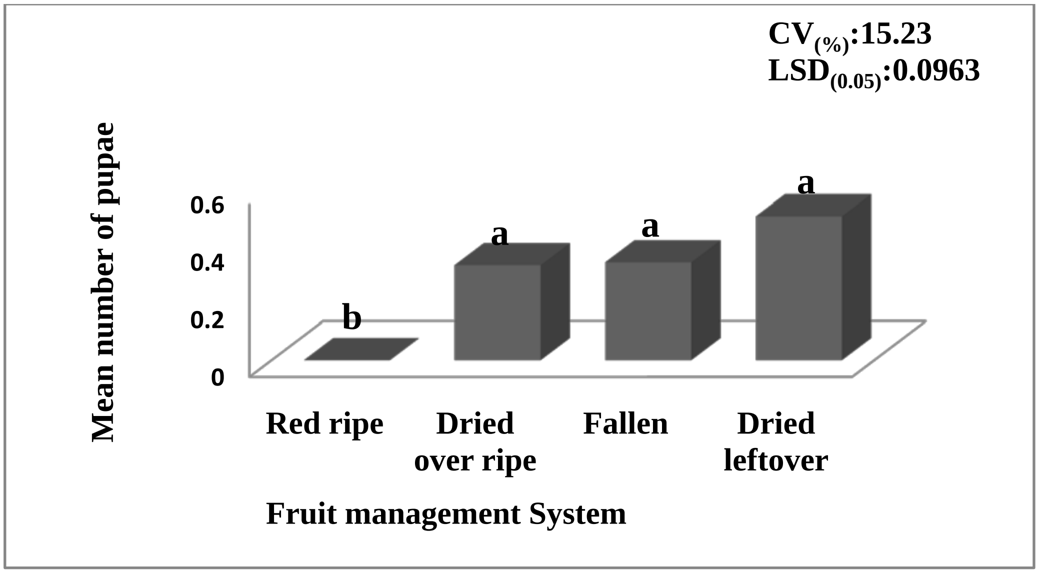

Figure 4: Mean number of pupae of coffee berry borer per damaged berry as influenced by fruit management System

Values in parentheses represent the transformed data $(x+0.5)^{1/2}$ and bars capped with same letter(s) are not significantly different at $p=\geq 0.05$

In the current study, the interaction of different locations with berry development stages resulted in maximum mean number of larvae (4.11) at Baya on dried leftover berries and the lowest value (0.11) at the same location on red ripe cherries, but no damage or larva recorded at Shone and Anderacha for red ripe cherries (Table 6). Similar to the other developmental stages of the borer, mean number of larvae was high at Baya on dried leftover cherries, which was next to adult borer. Larval stage of the beetle is known for feeding and making galleries inside the beans that directly contribute to yield loss up to total damage of the beans. This indicates that the presence of high number of larvae contributed to more yield losses at Baya than other locations. Similarly, Vega (2006) has reported that larval feeding on the endosperm greatly reduces quality and yields and can also cause abscission of the berries. Reid (1983) has also described loss of CBB caused mainly by the developing larva feeding on the beans. In addition, indirect loss of quality and quantity may also result from the activity of secondary pathogens and the fragmentation of beans during processing.

The maximum mean number of (7.55) adult beetles was also recorded at Baya on dried leftover berries and the lowest mean value (0.63) was observed at Anderacha on fallen berries, but no damage or adult beetle was recorded at Anderacha on red ripe cherries (Table 6). Baker and Barrera (1993) and Esayas *et al.* (2004) have also reported higher number of adult borer in dry leftover berries than in fallen berries on ground.

Table 6: Interaction effect of location and fruit management system on the mean number of larvae and adult CBB per damaged coffee berries

Location	Berry development stage	Larvae (Mean number / berry)	Adult beetles (Mean number / berry)
Baya	Red ripe	0.13 (0.78)[h*]	1.65 (1.46)[cd]
	Dried over ripe	3.65 (2.03)[ab]	3.40 (1.97)[b]
	Fallen	2.60 (1.76)[bcd]	2.17 (1.63)[c]
	Dried leftover	4.11 (2.14)[a]	7.55 (2.84)[a]
Shone	Red ripe	0.00 (0.71)[h]	0.89 (1.15)[ef]
	Dried over ripe	2.37 (1.69)[cde]	1.98 (1.570)[cd]
	Fallen	1.61 (1.45)[ef]	1.32 (1.35)[de]
	Dried leftover	3.11 (1.90)[abc]	3.45 (1.98)[b]
Anderacha	Red ripe	0.00 (0.71)[h]	0.00 (0.71)[g]
	Dried	1.18 (1.28)[fg]	0.79 (1.13)[ef]
	Fallen over ripe	0.80 (1.12)[g]	0.63 (1.06)[f]
	Dried leftover	2.04 (1.59)[de]	1.81 (1.52)[cd]
$LSD_{(0.05)}$		0.3020	0.2497
CV $_{(\%)}$		11.88	9.17

Values in parentheses represent the transformed data $(x+0.5)^{1/2}$ and means followed by same letter(s) within a column are not significantly different at $p=\geq 0.05$

The presence of more numbers of adult borers on coffee berries resulted in increased number of entrance holes into the berries, oviposition of more eggs and eventually an increase in the level of infestation and damage of the berries. In another study, Esayas *et al.* (2005) indicated that number of adult borers per damaged berry ranges from 1 to 55 where most of damaged berries harbored 1 to 20 adult borers per berry. Similarly Reid (1983) recorded 2 to 55 adult borers per berry on fallen berries.

4.1.5 Color of beans damaged with coffee berry borer

The effect of different locations and berry developmental stages and the interaction between the two showed highly significant (P<0.0001) difference on the color of damaged and discolored bean (black, blue-green and light gray bean). However, coffee production system and its interaction with the other treatments were not significant (P>0.05) (Appendix Table 2).

The highest mean of discolored beans (64.91) (62.73 to 67.79%) was at Anderacha on fallen berries and the lowest (38.38%) value was recorded at Shone on red ripe cherries, but no damage of CBB nor discolored beans recorded at Anderacha on red ripe cherries (Table 7). On the other hand, the highest mean of 47.24% and 45.77% light gray beans observed at Baya on dried over ripe and red ripe berry, respectively and 45.47% at Anderacha on dried over ripe berries. But the lowest mean of 35.26% light gray bean (33.21 to37.27%) recorded at Anderacha (1400m.a.s.l.) on fallen berry development stage and no damage or light gray beans observed at Anderacha on red ripe berries (Table 7). In the same way, the interaction showed the highest mean percentage of discolored beans at higher elevation (Anderacha) for fallen berries, whereas the highest mean value of light gray damaged beans was observed at low elevation (Baya) on dried over ripe cherries. The high percentage of discolored beans of fallen berries at high elevation showed the contribution of moisture and cool environmental condition to the partial decomposition of CBB damaged beans or to the development of black staining secondary micro-organisms.

The highest proportion of damaged and discolored beans was observed on fallen berries at high elevation where the lowest value was recorded on red ripe cherries. The discoloration of borer damaged beans fallen on the ground was related to relative by more moisture absorption and decaying of the berries. As previously stated, secondary infection of micro-organism and staining and blackening of bean might have been more facilitated on the ground. Early attack of borer can also cause blue-green staining of coffee beans on the tree. Similarly, light gray color of damaged beans was observed at all berry development stage with high percentage on dried over ripe cherries at Baya and at Anderacha on dried over ripe berries.

Table 7: Effect of interaction between location and fruit management system on the mean percentage of discolored and light gray beans damaged by coffee berry borer

Location	Fruit management system	Discolored beans (%)	Light gray beans (%)
Baya	Red ripe	54.23^{ab}	45.77^{a}
	Dried over ripe	52.78^{b}	47.22^{a}
	Fallen	57.56^{ab}	42.44^{ab}
	Dried leftover	57.50^{ab}	42.50^{ab}
Shone	Red ripe	38.38^{c}	43.3^{ab}
	Dried over ripe	54.59^{ab}	45.41^{ab}
	Fallen	61.00^{ab}	39.00^{ab}
	Dried leftover	57.88^{ab}	42.13^{ab}
Anderacha	Red ripe	0.00^{d}	0.00^{c}
	Dried over ripe	54.53^{ab}	45.47^{a}
	Fallen	64.91^{a}	35.26^{b}
	Dried leftover	60.12^{ab}	39.87^{ab}
LSD $_{(0.05)}$		12.12	10.19
CV $_{(\%)}$		13.36	14.71

Means with same letter(s) within a column are not significantly different

Coffee beans may show discoloration in response to borer attack as a result of natural physiological reaction or/and secondary infection of micro-organism entering through the hole of borer (Plate 2, Plate 3). When the hole created by the damage of borer is integrated with the color change of beans, it would be more responsible for quality deterioration. In line with this, Cavaco-Bicho (2008) reported that grain color is an important criterion for its valorization, acceptance or reject. McNutt (1975) as cited by Waterhouse (1998), Wrigley (1988) and CABI (2006) have reported that coffee beans damaged or even slightly bored by CBB acquire a distinctive blue-green staining which significantly reduces their market value.

Plate 2: Damaged and discolored coffee bean

Plate 3: A well processed and handled bluish bean color of coffee

Source: Teppi coffee plantation (2011) unpublished

In the study area, at coffee growing farmer's level, almost all of them sell their products before dehusking (hulling) of the berries. For this reason, the presence of different type of damaged discolored bean and number of holes possibly contribute to only reduction of yield (weight losses). But, when the product reached on the hand of trader, hulling of the berries and removing of all insect attacked bean from hulled berries (from other clean bean) was the main working criteria (obligation) for trader which inspected by marketing section of Ministry of Agriculture. Subsequently, this incurs cost to picking of insect attacked beans (more of borer damaged beans) and other defects from the clean beans (Plate 4). In area trader pay 80-100 Ethiopian birr for pickers (mostly women) to picking of defect from 100Kg of hulled beans (Trader, personal communication).

Plate 4: Workers picking insect attacked and defected coffee beans after hulling processes

If insect attacked beans reach to Ethiopia Commodity Exchange (ECX) market, during preliminary unwashed coffee raw evaluation (accounting for 40% of the total quality), total the presence of more than two holes into a bean would be considered as severe insect damage and, thus, categorized as primary defect of coffee. But, if the number of holes into bean are less than or equal to two, it is considered as slight insect damage and categorized as secondary defect. In case of sever insect damage, five insect damaged bean can be taken as one defect, ten damaged bean as two defects, …etc form 350gm sample of coffee. But, if the insect damaged beans integrate with black or blue-green staining color or fungus development, one black or blue-green insect damaged bean can be considered as one defect. As a result, if the summation of defects reach 6-10, 11-15, 16-20, 21-25, and greater than 25 defects, it would contribute to the reduction of 3, 6, 9, 12, 13.5% of raw value, respectively, from the total value given to primary defect (15%)(Kosalos *et al.*, 2004; ECX, 2011). Kosalos *et al.* (2004) have also reported the effect of insect damaged bean on cup quality that, insect damaged beans cause varies impact on the appearance of roasted coffee beans and can result in dirty, sour, or moldy flavors, especially if present in high quantity.

4.6 Correlation Analysis

The result of correlation analysis shows that CBB damage percentage was positively and highly significantly correlated to numbers of holes into beans ($r=0.97^{**}$), weight losses of berries ($r=0.98^{**}$), numbers of adult borers ($r=0.95^{**}$) and other CBB developmental stages. This correlation indicates that percentage damage of coffee berries by CBB has contributed to the presence of higher number of holes, weight losses of damaged berries and more number of adults and other developmental stages of the borer (Table 8).

In the present study the correlation number of holes into beans showed positive and highly significant correlation with damage percentage of berries (r=0.97), weight loss of berries (r=0.97) and numbers of adult borers in the bean (r=0.93) (Table 8). Similarly, Damon (2000) has reported that damage or galleries into the endosperm of the coffee seed cause economic losses. Furthermore, it was observed that percent weight loss of coffee berries has positive and highly significant correlation to damage percentage of coffee berries (r=0.98**), number of holes into beans (r=0.97**), number of adult borer beetles in damaged coffee berries (0.96**) and other borer development stages (Table 8). The correlation result indicates significant contribution of damaged berries, number of holes and number of adult borers to the weight losses of damaged coffee berries.

The number of eggs showed positive and highly significant relation to number of larvae (r=0.90**), number of pupae (r=0.73**), number of adult beetles (r=0.86**), percent weight loss of damaged berries (r=0.86**), numbers of holes into beans (r=0.85**) and percent damaged berries (r=0.85**). In the same way, number of larvae has positive and highly significant correlation with number of pupae (r=0.70**), number of adult borer (r=0.79**), weight loss of damaged berries (r=0.82**), number of holes into beans (r=0.80**) and damage percentage of berries (r=0.83**). Number of pupae has also positive and significant relations with number of adult beetles (r=0.68**), weight loss of damaged berries (r=0.69**), number of holes into beans (r=0.67**) and percent damaged of coffee berries (r=0.70**). Similarly, the number of adult borer was positively and highly significantly correlated to percent weight loss of damaged berries (r=0.96**), number of holes into beans (r=0.93**) and percent damage of coffee berries (0.95**) (Table 8).

Table 8: Pearson correlation among response variables

	DM	NH	WL	NE	NL	NP	NA	DBC	LGBC
DM	1	0.97^{**}	0.98^{**}	0.85^{**}	0.83^{**}	0.70^{**}	0.95^{**}	0.03^{ns}	0.27^{*}
NH		1	0.97^{**}	0.85^{**}	0.80^{**}	0.67^{**}	0.93^{**}	0.06^{ns}	0.34^{*}
WL			1	0.86^{**}	0.82^{**}	0.69^{**}	0.96^{**}	0.001^{ns}	0.29^{*}
NE				1	0.90^{**}	0.73^{**}	0.86^{**}	0.11^{ns}	0.39^{*}
NL					1	0.70^{**}	0.79^{**}	0.20^{ns}	0.38^{*}
NP						1	0.68^{**}	0.05^{ns}	0.24^{*}
NA							1	-0.06^{ns}	0.39^{*}
DBC								1	0.13^{ns}
LGBC									1

*DM=damage (%), NH= number of hole per bean, WL= weight loss (%), NE= number of eggs, NL= number of larvae, NP= number of pupae, NA= number of adult, DBC= discolored bean, GBC= light gray bean, **= highly significant, *= significant, ns= none significant*

Part II: Responses of DAs, Farmers and Enterprise experts

4.2 Perception, knowledge and management practices of farmers DAs and employees of plantation about coffee berry borer

4.2.1 Farmers perception, knowledge and management practices of coffee berry borer

Background of the respondents: 90.5% male and 9.5% female coffee farmer respondents were included for perception, knowledge and management practices assessment (Appendix Table 3). Respondents 38%, 33%, 18.5%, 7% and 3.5% in the age ranges of 41-50, 30-40, 51-60, >61 and <30 years old were, respectively. Most of respondent farmers were well-known for coffee production for the last many years. The education level of respondents indicates 11% illiterate, 58.5% from grade 1-4, 21.7% from grade 5-8, 1.6% from grade 9-10, and 1% from grade 11-12 (Appendix Table 4). Farmers not only depend upon coffee production, they also produce cereals (maize and sorghum), spices (turmeric and ginger), vegetables (onion, cabbage, carrot, bit root and others) and fruits (mango, avocado, banana, papaya and others). But, coffee is their main income source. Respondents' type of coffee farm includes 53% semi-forest coffee, 27.5% garden coffee, 12% small scale plantation coffee and 7.5% semi-forest and garden coffee, with majority having farm size between 0.25 ha and 2 ha of coffee. All of the respondents use weed control at least once per cropping season by using only slashing (55.5%), hoeing and slashing (31.5%), hand weeding and slashing (11%) and other methods (2%). Greater than 85% of coffee farmer respondents were prepared and sold their coffee as dried berries and less than 15% as red ripe stage for wet processing.

Farmers harvesting practices: stage of coffee berry development at which farmers harvest the crop and the frequency of harvesting due to the nature of different bearing time was varies among the respondents. Data obtained from the respondents reflect that 61.5% of the respondents collect the products at red ripe, dried over ripe from the trees and fallen berries from the ground, 18.5 % respondents harvest at red ripe and dried berries from the trees, 18% at all stage (including green mature), 1% dried over ripe berries from the tree and 1% fallen berries from ground (Table 9). With regard to frequency of harvesting, most respondents (61.5%) harvest more than three times and 38.5% harvest their products three times in one cropping season (Appendix Table 5).

Data on harvesting stage of coffee berries indicates that most of the farmers harvest at dried over ripe stage and fallen berries from the ground with minimum mixing of red ripe cherries. As indicated earlier dried over ripe and fallen berries on the ground can be damaged by coffee berry borer with incidence of 1.00-16.67% and 0.33-12.34%, respectively. So, it is possible to conclude that farmers harvesting stage might have contributed to the damage (incidence) of coffee berry borer. On contrary, harvesting frequency (greater than three times) is a good practice even to control CBB, but the problem with harvesting frequency is it does not coincide with recommended berry development stage. Similarly, Saldarriaga (1994) and Bustillo *et al.* (1998) as cited by Aristizabal (2011) indicated that labor intensive, regular harvesting and sanitation of mature berries removes developing coffee berry borers before they emerge to start another life cycle.

Table 9: Stage of berry development at which farmers and plantation enterprises harvest their coffee

Respondents		Stage of harvesting coffee berry					Total
		Dried berry from the tree	Fallen coffee berry from ground	Red ripe and dry berry from the tree	Red ripe, dried from the tree and fallen from the ground	All stage	
Farmer	Count	2	2	37	123	36	200
	%	1	1	18.50	61.50	18	100
Enterprise expert	Count	0.00	0.00	22	2	0.00	24
	%	0.00	0.00	91.70	8.30	0.00	100
Total	Count	2	2	59	125	36	224
	%	0.90	0.90	26.30	55.80	16.10	100

The perception or/and knowledge of farmers: in response to the questionnaire 87% (174 farmers) of respondents did mentioned any observation of holes into coffee berry or beans. Also from 13% (26 farmers) respondents, those who had observation of holes into coffee berries or beans 57.7% of 13% (15 respondents) did not know the exact cause of the holes into coffee berry or beans (Table 10 and 11). Also data obtained from the respondents indicate that 99.5% of respondents did not training from development agents (DA) about CBB and its control measures. Even including 0.5% respondent (one person) who responded as he had got training from DA, all respondents did not apply any control measures (Table 12). This result showed almost very low (nil) perception and knowledge of farmers about CBB and its control measures. This lack of perception and knowledge might arise from farmers' less concentration like to small holes into beans (less visible), farmers' selling his product before dehusking (hulling) and poor extension service particularly on crop protection. In the respondents area the leftover coffee berry on the tree was estimated to be less than 5% (personal observation). This reduced leftover of coffee and might the presence of natural enemies contribute for the reduction of CBB. Chemeda *et al.* (2011) has reported the presence of natural enemies (*Prorops nasuta*) near survey area (Berhane-Kontir forest coffee).

4.2.2 Perception, knowledge and management practices of Development Agents toward coffee berry borer

Background of development agents: 73% of the development agents served in the survey area for more than two years, whereas 26.7% had less than two years experience. All of the respondents had educational level of 10+3 (diploma) in plant sciences (53.3%), natural resource management (26.7%) and animal science (20%) (Appendix Table 4), but all DAs are working as a general agricultural extension workers or agents.

Perception, knowledge and extension services of DA: 53.3% of the respondents did not observe any kind of holes into coffee berries or beans (Table 10). Out of 46.7% respondents, those who had observation of holes into berries and beans were 14.3% but they did not know the exact cause of the holes, but 85.7% of 46.7% respondents respond that the cause of the holes was due to insect attacks. From those who had observation 16.7% of them got information from personal observation, 33.3% from agricultural office and 50% had got information from other sources (including formal education). Similarly, from total respondents only 13.3% of DAs applied CBB control measures and integrates CBB control measures with other activities of extension services (Table 11 and 12). All respondents reflected that they were not asked about CBB problem by the farmers.

Table 10: Status of awareness of different stakeholders about damage by berry borer on coffee berries and beans

Respondent type	measurement	Awareness observation of DAs, experts at plantation Enterprises and farmers about holes into coffee bean/berry		Total	Chi-square (x^2)	P-value
		Yes	No			
Farmer	Count	26	174	200	52.65	<0.0001
	%	13	87	100		
DA	Count	14	16	30		
	%	46.67	53.33	100		
enterprise expert	Count	17	7	24		
	%	70.80	29.20	100		
Total	Count	57	197	254		
	%	22.44	77.56	100		

****Significant at 1%, **Significant at 5%, *Significant at 10%, ^{ns} non significant*

In this study it was noted that, the perception and knowledge of development agents was very poor and not in a position to identifying CBB, its damage symptoms and unable to teach farmers about possible control measures of the pest. Even those with little knowledge about the pest did not give attention to train farmers and took some control measures toward minimizing the incidence of CBB. For some extension agents, their fields of study (animal science 20% and natural resources 26.67%) might have contributed for the lack of perception and knowledge about CBB.

Table 11: knowledge and information of respondent about CBB

Tasks		Farmers (N=200)		DAs (N=30)		Enterprise experts (N=24)		Chi-square	p-value
		count	%	count	%	count	%		
-What is the cause for holes into berry/bean (from those having observation of holes)	-Insects	11	42.3	12	85.7	17	100	18.49	<0.0001
	-I do not know the cause	15	57.7	2	14.3	0	0		
-Do you have information about CBB	-Yes	1	0.5	12	40	17	70.8	1.25	<0.0001
	-No	199	99.5	18	60	7	29.2		
-Source of information from	-Personal observation	0	0	2	16.7	6	35.3		
	-DA	1	100	0	0	0	0		
	-Agricultural office	0	0	4	33.3	0	0		
	-Research center	0	0	0	0	5	29.4		
	-Training	0	0	0	0	2	11.8		
	-Other source (formal education)	0	0	6	50	4	23.5		

****Significant at 1%, **Significant at 5%, *Significant at 10%, ^{ns} non significant*

In general the possible reason to poor perception, lack of knowledge about the CBB and absence of its control measures among the development agents and farmers might be due to lack of awareness by concerned government organizations, lack of dissemination of research output to the extension service, underestimating of the problem of CBB by Ministry of Agriculture (MOA), lack of training to improve the skill of development agents on CBB, unrelated field of study of DA to provide extension service, given less attention for crop protection and other minor factors.

Table 12: Response of respondents pertaining to training and control measures related to CBB

Tasks		Respondents					
		Farmers (N=200)		Development Agents (N=30)		Enterprise experts (N=24)	
		Yes	No	Yes	No	Yes	No
-CBB problem raised by farmer	Count	-	-	0	30	-	-
	%	-	-	0	100	-	-
-Integrating CBB with other extension service	Count	-	-	4	26	-	-
	%	-	-	13.3	86.7	-	-
-Were you trained by DA about CBB	Count	1	199	-	-	-	-
	%	0.5	99.5	-	-	-	-
-Did you train farmers	Count	-	-	4	26	-	-
	%	-	-	13.33	86.67	-	-
-Did you know CBB control measures	Count	1	199	4	26	6	18
	%	0.5	99.5	13.3	86.7	25	75
-Application and assisting control measures	Count	0	200	4	26	6	18
	%	0	100	13.3	86.7	25	75

4.2.3 Perception, knowledge and management practices of experts from coffee plantation enterprise

Background of coffee plantation enterprise experts: The respondents of coffee plantation enterprise were selected from substations of the farms. About 79% of respondents had education level of diploma (12+2; 10+3) and the rest 20.8% had B.Sc. of which 79.2% have plant science/horticulture and 20.5% have general agriculture. According to all respondents, 100% weed control (by using slashing and herbicide) and pruning (maintenance and few stumping) is being done in the enterprise. Also 91.7% of the respondents indicated that harvesting is done at red ripe and dried over ripe fruit stage from trees, but 8.3% respondents mentioned harvesting of red ripe and dried over ripe fruits from the tree and fallen berries from the ground (Table 9). 54.2% respondents also indicated that harvesting is done three times, 37.5% two times, and 8.3% of respondents indicate that it is done more than three times (Appendix Table 5). Concerning availability of labor 70.8% of respondents respond the presence of average level of labor force, but 29.2% respondent agree with the presence of few labor forces (insufficient) for harvesting products at peak harvesting time. Similarly 25%, 29.1%, 41.7% and 4.2% respondents suggest that <10%, 11-20%, 21-30% and >30% leftover crop in the farm, respectively (Table 13), due to shortage of labor force during harvesting period.

Table 13: The availability of labor force and the estimate of leftover in large scale plantation

	Response option	Enterprise experts (N=24)	
		counts	%
Labor force to harvesting	Few	7	29.2
	Average	17	70.8
	Fit with need(high)	0	0
Leftover in the farm	Yes	24	100
	No	0	0
Estimate of leftover in the farm	<10%	6	25
	10-20%	7	29.1
	21-30%	10	41.7
	>30%	1	4.2

Perception and knowledge of enterprise experts: 70.8% of the respondents had observation on the holes into the berries and beans, but 29.2% did not have any observation of holes into berry or beans. All those respondents who had observation of holes mentioned that insect is the cause of holes into the berries or beans and 35.3%, 29.4%, 11.8% and 23.5% of respondents got information about coffee berry borer from personal observation, research center, training, and other sources, respectively. But, only 25% of the respondents mentioned about application of control or management measure of CBB.

Because of the high incidence of CBB in the area, a better perception and knowledge was reflected by the coffee plantation expert respondents. However, according to the respondents the action being taken to reduce the damage of CBB is minimum. On the other hand, the higher percentage of leftover cherries in coffee plantations of the enterprise indicates the risk of infestation of CBB year round and buildup of CBB population that might be a danger or threat not only for that particular plantation, but also for the surrounding farmers' small coffee holdings.

5. SUMMARY AND CONCLUSION

CBB is one of the important insect pests of coffee, which is known to cause damage both in terms of yield loss and quality deterioration. Therefore, the present study was conducted to assess the level of infestation by coffee berry borer under different production systems, and at various locations and berry development stages. Moreover, the objective of this study was to assess perception, knowledge, and management practice of farmers, Development Agents and different experts with regard to the control of coffee berry borer.

The present study confirmed the distribution of coffee berry borer over a wide range of altitude, from 1110m.a.s.l (Baya) to 1720m.a.s.l (Anderacha). The result of the study indicated that 37.50 % of mean damage by CBB occurred on dried leftover berries at Baya and 0.50% (the lowest mean damage) on red ripe cherries at Shone, but no damage was observed on red ripe cherries at Anderacha. The highest damage due to berry borer was observed in plantation coffee stands. Furthermore, dried leftover berries showed high susceptibility to the damage by borer, unlike the red ripe cherries which were little attacked by CBB. Hence, early and effective harvesting of coffee cherries at red ripe stage is crucial to reduce the infestation and damage of CBB.

The current research revealed that, the highest mean numbers of (10.88) holes into beans was recorded at Baya on dried leftover berries and the lowest (0.83) on red ripe berries at Shone. Likewise mean minimum and maximum weight loss percentage of 0.17 and 8.11 were observed on red ripe berries at Shone and on dried leftover berries at Baya, respectively.

With regard to mean number and stage of CBB, the highest mean number of (2.44 and 2.62) eggs, and (0.55 and 0.50) pupa was observed at Baya and on dried leftover berries, respectively. Similarly, the highest mean number of (4.11) larvae and (7.55) adults was recorded at Baya on dried leftover berries. Therefore, lower elevation (Baya) and dried leftover berries were favorable as harboring and overwintering place for the borer and used as main source of infestation for the next cropping season. Hence, removing of dried leftover berries is important to CBB management.

It was observed that mean percentage of damaged and discolored beans increased along with the increase in elevation and, thus, the highest percentage was observed on fallen berries at Anderacha. On the other hand, the highest mean proportion of damaged light-gray bean was observed at all berry development stages with high percentage on dried over ripe cherries at Baya and on dried over ripe cherries at Anderacha. Hence, location and berry development stage should be considered in relation with damage of CBB to take management measures and reduce or minimize quality deterioration.

In the present study, it was observed that more than 87% of coffee farmers have not seen holes into coffee berries/beans and, hence, 100% of them do not apply any management measures. Similarly, 53.3% of development agents and 29.2% of enterprise experts have no previous knowledge about the symptom of CBB damage and only 13.3% development agents and 25% of enterprise experts applied CBB control measures and the same percent of DA integrates CBB management measures with other activities of extension services. Lack of proper perception and knowledge regarding CBB damage around coffee farmers, extension service providers (DA) and enterprise experts is among critical problems toward CBB management. Therefore, due attention should be given by concerned government organizations (e.g. Ministry of agriculture, plant health clinics, research centers etc) and others to create awareness about CBB and development of sustainable pest management methods for control of CBB.

As a follow up work, multi-location study involving different coffee management systems like forest and semi-forest coffee, and all berry development stages could be suggested to come up with full recommendation. Moreover, a detailed study would be required in to

- The biology and ecology of berry borer in Ethiopia,
- Study and setting economical threshold level of CBB,
- Screening and selection of cultivars for resistance to berry borer,
- Designing the best management measures to reduce infestation and damage from the pest,
- Survey and identification of the potential natural enemies of coffee berry borer and
- Quantifying the impact of CBB on the national economy in general and on the coffee sector in particular should similarly deserve due attention by further research works.

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7. APPENDIX

Appendix Table 1: Mean square values for damage percentage (DM), number of holes (NH) into beans, weight losses (WL) percentage, number of eggs (NE) and numbers of larvae (NL)

Source	Degrees of freedom	Mean square values				
		DM (%)	NH(average number)	WL (%)	NE(average number)	NL(average number)
L	2	1078.99^{**}	4.86^{**}	4.10^{**}	2.13^{**}	1.52^{**}
MS	1	216.04^{**}	0.03^{ns}	0.07^{**}	0.02^{ns}	0.06^{ns}
BD	3	1622.67^{**}	7.00^{**}	5.86^{**}	2.51^{**}	4.44^{**}
L*MS	2	0.37^{ns}	0.009^{ns}	0.0005^{ns}	0.01^{ns}	0.02ns
L*BD	6	77.68^{**}	0.51^{**}	0.48^{**}	0.04^{ns}	0.14^{*}
MS*BD	3	19.55^{**}	0.007^{ns}	0.02^{**}	0.003^{ns}	0.0005ns
L*MS*BD	6	0.77^{ns}	0.01^{ns}	0.02^{ns}	0.002^{ns}	0.0009ns
Block	2	0.8985^{ns}	0.029^{ns}	0.0014^{ns}	0.022^{ns}	0.0034^{ns}
Error	12	0.77	0.15	0.0009	0.03	0.03
CV (%)		6.10	6.46	2.20	12.20	11.88

Appendix Table 2: Mean square values for numbers of pupae (NP), numbers of adults (NA), discolored damaged bean and light gray damaged bean color

Source	Degree of freedom	Mean square values			
		NP(average number)	NA(average number)	Discolored beans (%)	Light Gray bean color (%)
L	2	0.35^{*}	4.59^{**}	689.90^{**}	1413.97^{**}
MS	1	0.008^{ns}	0.04^{ns}	35.01^{ns}	28.74^{ns}
BD	3	0.23^{*}	3.31^{**}	3634.27^{**}	896.19^{**}
L*MS	2	0.001^{ns}	0.0007^{ns}	55.25^{ns}	55.81^{ns}
L*BD	6	0.05^{ns}	0.18^{*}	1261.48^{**}	851.81^{**}
MS*BD	3	0.002^{ns}	0.004^{ns}	9.96^{ns}	55.94^{ns}
L*MS*BD	6	0.0006^{ns}	0.006^{ns}	71.39^{ns}	45.16^{ns}
Block	2	0.00026^{ns}	0.0077^{ns}	125.08^{ns}	27.74^{ns}
Error	12	0.18	0.02	46.38	32.83
CV (%)		15.23	9.17	13.36	14.71

Appendix Table 3: the number and sex of respondents

Respondent type	Unit	sex of respondent		Total
		Male	Female	
Farmer	Count	181	19	200
	%	90.5%	9.5%	100.0%
DA	Count	26	4	30
	%	86.7%	13.3%	100.0%
Enterprise expert	Count	22	2	24
	%	91.7%	8.3%	100.0%
Total	Count	229	25	254
	%	90.2%	9.8%	100.0%

Appendix Table 4: Respondents field of studies

Respondent type		Field of study of respondents													Total
		Plant science/ Horticulture		Animal science		Natural resource		General agriculture		None Professional In grade					
		10+3(dip.)	Bsc	10+3(dip.)	Bsc	10+3(dip.)	Bsc	10+3(dip.)	Bsc	Illiterate	1-4	5-8	9-10	11-12	
Farmer	Count	-	-	-	-	-	-	-	-	22	117	55	4	2	200
DA	Count	16	-	6	-	8	-	-	-	-	-	-	-	-	30
enterprise expert	Count	14	5	-	-	-	-	5	-	-	-	-	-	-	24
Total	Count	30	5	6	-	8	-	5	-	22	117	55	4	2	254
	%	11.81	1.97	2.36	-	3.15	-	1.97	-	8.66	46.06	21.65	1.58	0.79	100

Appendix Table 5: The harvesting frequency at farmers and large scale plantation level

Respondents		Frequency of harvesting			Total
		Twice	Three times	More than three times	
Farmer	Count	0	77	123	200
	%	.0%	38.5%	61.5%	100.0%
Enterprise expert	Count	9	13	2	24
	%	37.5%	54.2%	8.3%	100.0%
Total	Count	9	90	125	224
	%	4.0%	40.2%	55.8%	100.0%

Appendix questioner

I. Questioner designed to collect information from farmers about perception, knowledge and management practices of CBB, and related agronomic practices

1. Personal information
   - ✓ Name of farmers ___________________________Sex_________ age_______
   - ✓ Marital status_______________________
   - ✓ Family status № of families __________male_________ female__________
   - ✓ Educational status _______________
   - ✓ Kebele _______________ woreda_______________ zone_______________

2. Coffee farm of under interviewer farmer

   - ✓ Size of farm _________ha
   - ✓ Type of coffee farm
     - A. Forest coffee
     - B. Semi-forest coffee
     - C. Garden coffee
     - D. Plantations
   - ✓ Variety of coffee plants
     - A. Local
     - B. Improved
     - C. Both
   - ✓ Age of coffee farm/plantation
     - A. <6 years
     - B. 7 to 15 years
     - C. 16 to 25 years
     - D. >25 years

3. Cultural practice of farmers

   - ✓ Did he/she weed or cultivate his/her coffee farm?
     Yes-----------No -------------
   - ✓ If yes, type of weeding

G. Hand weeding
H. Slashing
I. Hoeing
J. Herbicide
K. A and B
L. A and C
A. A and D
B. B and C
C. B and D
D. C and D
E. B, C and D
F. All of above practices

- ✓ Did he/she prune his/her coffee farm?

Yes----------No--------------

- ✓ If the answer is yes, what type of pruning?

A. Formative pruning
B. Maintenance pruning
C. Rejuvenation/stumping
D. A and B
E. A and C
F. B and C
G. All of above practices

4. Major time of flowering (month of flowering) of coffee at area

A. December to mid January
B. January to February
C. February to March
D. I don't Know or remember the exact time of flowering

5. Month of full maturity or red ripe

A. June to July
B. August to September
C. September to October
D. October to mid November
E. I don't Know or remember the exact month of maturity

6. Month of full dried berry stage

A. Mid September to mid October
B. Mid October to mid November
C. Mid November to mid December
D. I don't Know or remember the exact month

7. Farmers harvesting practices used

- ✓ Methods of harvesting

A. Unselective Strip picking
B. Selective picking only red ripe cherries
C. Picking over dried cherries
D. Collecting by hand shaking coffee trees and from ground
E. A and B
F. A and C
G. A and D
H. B and C
I. B and D
J. C and D
K. All methods are used

- ✓ At what stage of coffee berry development stage harvested?

A. Green mature stage
B. Red ripe stage
C. Dried berry from the tree
D. Fallen berry from the ground
E. A and B
F. A and C
G. A and D
H. B and C
I. B and D
J. C and D
K. At all stage

- ✓ Frequency of harvesting used per one cropping season

    A. Once
    B. Twice
    C. Three times
    D. More than three times

8. Farmers/owner's allocation of their harvested coffee product

    - ✓ For home consumption
        A. ≤5%
        B. From 6 to 10%
        C. From 11to 15%
        D. ≥16%
        E. No allocation to home consumption
    - ✓ Total allocation of his/her product for wet processing
        A. <10%
        B. From 10 to 20%
        C. From 21 to 30%
        D. From 31 to 50%
        E. From 51 to 75%
        F. >75%
        G. No allocation to wet processing
    - ✓ Total allocation of his/her product for dried cherry
        A. <10%
        B. From 10 to 20%
        C. From 21 to 30%
        D. From 31 to 50%
        E. From 51 to 70%
        F. From 71 to 85%
        G. >85%
        H. No allocation to dried cherry

9. What type of pest they have?
    A. Pathogens
    B. Insect pests
    C. Weeds
    D. Pathogen and insect pest
    E. Pathogen and weed
    F. Insect pest and weed
    G. All of the above

10. Did he/she observe the hole on the tip of berry?
    Yes----------- No----------

    - ✓ If yes, what he/she understand about the hole?

        A. Pathogen effect
        B. Insect pest effect
        C. Mechanical injury
        D. Age of the berry
        E. I don't know the cause of it

11. Did he/she was observe the holes in to the beans?

Yes--------------- No---------------

- ✓ If the answer is yes, what he/ she understand about the hole in to beans?

A. Pathogen effect
B. Insect pest effect
C. Mechanical injury
D. Age of the berry
E. I don't know the cause of it

12. Did he/she have information about coffee berry borer?

Yes----------------No-----------------

- ✓ If yes, who is his/her source of information?

A. Personal observation
B. Neighbor coffee farmer
C. From extension agents
D. From agricultural office
E. From research centers
F. Training
G. From media
H. Other sources

13. Have you get training from DA about CBB and its control methods?

Yes------------- No----------------

- ✓ If yes. What control /management measure you took?

A. Cultural
B. Mechanical
C. Chemical
D. Cultural and mechanical
E. Cultural and chemical
F. Mechanical and chemical
G. All of the above
H. No control measures have been taken

14. What type of effect caused by the attack of CBB?

A. Quality losses
B. Yield losses
C. Reduction of prices
D. Both quality and yield loss

Notes: Environmental data will be taken from secondary source

II. Questioner designed to collect information from coffee plantation enterprise experts about perception, knowledge and management practices of CBB, and related agronomic practices

1. Personal information

- Name -----------------------------sex male---------------female----------------------
- Educational status(level) ------------------------Field of study-------------------
- How long you work in the area ---
- Position on the farm--

2. Cultural practice of enterprise

- ✓ Did they weed or cultivate the coffee farm?

  Yes-----------No -------------

- ✓ If yes, type of weeding

  A. Hand weeding
  B. Slashing
  C. Hoeing
  D. Herbicide
  E. A and B
  F. A and C
  G. A and D
  H. B and C
  I. B and D
  J. C and D
  K. B, C and D
  L. All of above practices

- ✓ Did they prune coffee farm?

  Yes----------No-------------

- ✓ If the answer is yes, what type of pruning?

  A. Formative pruning
  B. Maintenance pruning
  C. Rejuvenation/stumping
  D. A and B

3. Major time of flowering (month of flowering) of coffee
   A. December to mid January
   B. January to February
   C. February to March
   D. I don't Know or remember the exact time of flowering
4. Month of full maturity or red ripe
   A. June to July
   B. August to September
   C. September to October
   D. October to mid November
   E. I don't Know or remember the exact month of maturity

5. Month of full dried berry stage

   A. Mid September to mid October
   B. Mid October to mid November
   C. Mid November to mid December
   D. I don't Know or remember the exact month of maturity

6. Farmers harvesting practices used
   - ✓ Methods of harvesting
     A. Unselective Strip picking
     B. Selective picking only red ripe cherries
     C. Picking over dried cherries
     D. Collecting by hand shaking coffee trees and from ground
     E. A and B
     F. A and C
     G. A and D
     H. B and C
     I. B and D
     J. C and D
     K. All methods are used
   - ✓ At what stage of coffee berry development stage harvested?

     A. Green mature stage
     B. Red ripe stage
     C. Dried berry from the tree
     D. Fallen berry from the ground
     E. A and B
     F. A and C
     G. A and D
     H. B and C
     I. B and D
     J. C and D
     K. At all stage harvested
   - ✓ Frequency of harvesting used per one cropping season

     A. Once
     B. Twice
     C. Three times
     D. More than three times

7. What type of pest they have?
   A. Pathogens
   B. Insect pests
   C. Weeds
   D. Pathogen and insect pest
   E. Pathogen and weed
   F. Insect pest and weed
   G. All of the above
8. Did he/she observe the hole on the tip of berry?
   Yes----------- No----------

   - ✓ If yes, what he/she understand about the hole?

     A. Pathogen effect
     B. Insect pest effect
     C. Mechanical injury
     D. Age of the berry
     E. I don't know the cause of it

9. Did he/she was observe the holes in to the beans?

Yes--------------- No---------------

- ✓ If the answer is yes, what he/ she understand about the hole in to beans?

A. Pathogen effect
B. Insect pest effect
C. Mechanical injury
D. Age of the berry
E. I don't know the cause of it

10. Did he/she have information about coffee berry borer?

Yes----------------No-----------------

- ✓ If yes, .who is his/her source of information?

A. Personal observation
B. Neighbor coffee farmer
C. From extension agents
D. From agricultural office
E. From research centers
F. Training
G. From media
H. Other sources

- ➢ At what fruit developmental stage CBB starts to attack coffee berries

A. At green stage
B. At red ripe stage
C. At over ripe stage
D. At leftover stage
E. On the ground
F. At red ripe and above
G. At over ripe and above
H. At all stage

- ➢ At what stage the severity is becomes high?

A. At green stage
B. At red ripe stage
C. At over ripe stage
D. At leftover stage
E. When fallen on the ground
F. At all stage

11. What type of effect caused by the attack of CBB?

A. Quality losses
B. Yield losses
C. Reduction of prices
D. Both quality and yield loss
E. Both quality and price loss
F. Yield loss and price reduction
G. All of the above

12. Did you know any control measure?

Yes------------ No---------------

- If yes, what type of control measure (pest management system) they practices?
    - A. Cultural
    - B. Mechanical
    - C. Chemical
    - D. Cultural and mechanical
    - E. Cultural and chemical
    - F. Mechanical and chemical
    - G. All of the above
    - H. No control measures have been taken

13. How is the availability of labor force at harvesting time?

    - A. Few
    - B. Average
    - C. High

14. Is there a probability of left over berries on the tree / fallen berries on the ground, which cannot be collect?

Yes ------------No----------------

- If yes, how much the estimate of the product that cannot be collected?
    - A. <10%
    - B. 11-20%
    - C. 21-30%
    - D. >30%

<u>Notes</u>: - Environmental data will be taken from secondary source

III. Questionnaire designed to collect information from Development agents about perception, knowledge and management practices of CBB, and related agronomic practices

1. Personal information

- Name -----------------------------sex male---------------female-------------------
- Educational status(level) ------------------------Field of study---------------------------
- How long you work in the area
    - A. For < 2 years
    - B. From 2 to 3 years
    - C. From 3.1 to 5 years
    - D. > 5 years

2. Did he/she observe the hole on the tip of berry?

Yes----------- No----------

- ✓ If yes, what he/she understand about the hole?

    A. Pathogen effect
    B. Insect pest effect
    C. Mechanical injury
    D. Age of the berry
    E. I don't know the cause of it

3. Did he/she was observe the holes in to the beans?

   Yes--------------- No---------------

- ✓ If the answer is yes, what he/ she understand about the hole in to beans?

  A. Pathogen effect
  B. Insect pest effect
  C. Mechanical injury
  D. Age of the berry
  E. I don't know the cause of it

4. Did he/she have information about coffee berry borer?

   Yes----------------No-----------------

- ✓ If yes, .who is his/her source of information?

  A. Personal observation
  B. Neighbor coffee farmer
  C. From extension agents
  D. From agricultural office
  E. From research centers
  F. Training
  G. From media
  H. Other source

15. What type of effect caused by the attack of CBB?

    A. Quality losses
    B. Yield losses
    C. Reduction of prices
    D. Both quality and yield loss
    E. Both quality and price loss
    F. Yield loss and price reduction
    G. All of the above

5. How is the incidence in your working area?

   A. Increased
   B. Reduced
   C. Constant
   D. I don't observe/know the incidence

6. Do you know about the control measures

   Yes---------------------- No------------------

- If yes, what type of control measure (pest management system) you apply?
    - A. Cultural
    - B. Mechanical
    - C. Chemical
    - D. Cultural and mechanical
    - E. Cultural and chemical
    - F. Mechanical and chemical
    - G. All of the above
    - H. No control measures have been taken

7. Did you integrate CBB control measures to other activities?

   Yes-------------No------------------

8. Dose farmers ask you about CBB?

   Yes-------------No----------------

9. Did you teach farmers about CBB?

   Yes------------- No--------------

- If Yes,
    - ✓ What type of teaching methods you use?
        - A. Lecture type
        - B. Practical or demonstration type
        - C. Integration of the two
        - D. Others methods
    - ✓ At what frequency?
        - A. Once in month
        - B. Quarterly
        - C. Once in six month
        - D. Once in a year