INFLUENCE OF PRODUCTION SYSTEM, SHADE LEVEL AND ALTITUDE ON COFFEE INSECT PESTS AND BLOTCH MINER PARASITOIDS AT GERA-GOMMA, ETHIOPIA

MSc. THESIS

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DECEMBER, 2019

JIMMA, ETHIOPIA

Influence of Production System, Shade Level and Altitude on Coffee Insect Pests and Blotch Miner Parasitoids at Gera-Gomma, Ethiopia

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A Thesis Submitted to School of Graduate Studies, Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment for the Requirement of the Degree of Master in Plant Protection

December, 2019

Jimma, Ethiopia

APPROVAL SHEET

Jimma University College of Agriculture and Veterinary Medicine

<u>Thesis Submission for External Defense Request Form (F-07)</u>

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Program of the study: **Plant Protection (MSc)**

TITLE: Influence of Production System, Shade Level and Altitude on Coffee Insect Pests and Blotch Miner Parasitoids at Gera-Gomma, Ethiopia

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BIOGRAPHICAL SKETCH

The author was born in Sude, Arsi Zone of the Oromia Regional State in June 1992. He attended his Elementary education at Alola and Alemgena primary school from 2000-2006. The author studied his secondary school education from 2007 to 2010 at Kulla secondary and preparatory school, Arsi Zone. After taking Ethiopian Higher Education Entrance Qualification Certificate Examination in 2010, he then joined Ambo University in 2011 and graduated with a Bachelor of Science in Plant Sciences in June 2013. After his graduation, the author was employed by the Ethiopian Agricultural Research Institute, Jimma Agricultural Research Centerin October 2014 to September 2017. He served as junior researcher in Coffee Entomology research division, until he joined the postgraduate program of Jimma University to pursue his Master of Science degree in Plant Protection.

ACKNOWLEDGEMENTS

Above all, Praise and Glory to Almighty God, who gave me the fortune to pursue my study, and the strength to get through the rigors of the MSc study.

My deep and sincere gratitude go to my advisors Dr. Esayas Mendesil and Dr. Ayco Tack, for their keen interest, kindness, valuable guidance, comments as well as generous thoughts and encouragement offered to me starting from proposal preparation to the final thesis write up. They have taught me the methodology to carry out the research (my Thesis). It was a great privilege and honor to work and study under their guidance. They offered me so much advice, patiently supervising me, and always guiding me in the right direction. I have learned a lot from them, without their help I could not have finished my thesis successfully.

I am highly grateful to Beyene Zewdie, Irena Koelemeijer, Biruk Ayalew, Moritz Stuber, Desalegn Alemayehu, Meseret Tesfaye, Wakuma Merga, Bogale Ayana, Magersa Kebade, Teshome Mola, Belay Abate and Sisay Kidanu, for their very good support during data collection and I gained a lot from them, through their personal and scholarly interactions and encouragement throughout my study period.

I would like to extend my deepest gratitude to the Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center for allowing me the opportunity to pursue my MSc study, and SIDA for providing me all rounded services and materials with good working environment that facilitated my research work. Jimma University College of Agriculture and Veterinary medicine and all staff of horticulture and plant sciences (my instructors) are also acknowledged for giving me graduate study and for their lecturing in good way. Special thanks go to Gomma and Gera coffee growing farmers for allowing me to conduct the research on their coffee farm.

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
CBB	Coffee berry borer
CBM	Coffee berry moth
CLS	Coffee leaf skeletonizer
CPS	Coffee Production Systems
CSA	Central Statistical Agency
EARO	Ethiopian Agricultural Research Organization
ECTA	Ethiopian Coffee and Tea Authority
EIAR	Ethiopian Institute of Agricultural Research
FC	Forest Coffee
GDP	Growth Domestic Product
GLM	Generalized Linear Model
GLMM	Generalized Linear Mixed Model
GPS	Geographical Positioning System
ICO	International Coffee Organization
IPM	Integrated Pest Management
JARC	Jimma Agricultural Research Center
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
PC	Plantation Coffee
SFC	Semi Forest Coffee
SIDA	Swedish International Development Cooperation Agency
SLM	Serpentine leaf miner
SPC	Semi Plantation Coffee
USDA	United States Department of Agriculture

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ABSTRACT

Coffee is one of the most traded commodities worldwide, and it is an important export crop and millions of the people generate their livelihood. The crop suffers from many biotic and abiotic constraints resulting in low average national yield in Ethiopia. Insect pests are one of the factors responsible for low national yield. The objective of the present study was to determine the influence of production system, shade and altitude on leaf damaging, berry feeding, sucking insects and some gastropods and on blotch miner parasitoids in different coffee production systems. A total of 60 plots were assessed in wet and dry seasons of 2018/2019; under four coffee production systems, along different altitudes (1506 –2159) and shade canopy closure (13-83%). For the leaf damaging insect pests two branches were randomly selected from each of the 16 trees per plot and the total number of leaves and damaged leaves was counted. The same 16 trees were examined for presence/absence of the other coffee insect pests and gastropods. The relationship between parasitoids and predictor variables was determined. Production systems showed a significant effect on leaf damaging insects and increased with intensification. The percent infestation of coffee leaf skeletonizer (Leucoplema dohertyi) ranged from 4-84 and 18-60 during wet and dry season, respectively and no coffee trees were free from this pest during assessment. This insect was the most commonly and frequently detected among other leaf damaging insect pests. Shade canopy cover was negatively associated with coffee blotch miner (Leucoptera caffeina) and serpentine miner (Cryphiomystis aletreuta) in 2018/2019, respectively. As altitude increased the leaf damaging pests decreased. The highest (51.69%) and lowest (6.40%) parasitoids emerged from sample collected under semi forest and plantation coffee, respectively from the total population, while higher blotch miner adult moth was found in plantation coffee at low altitude. Parasitized larvae and emerged number of eulophids increased with altitude. Intensively managed coffee production systems significantly increased the abundance of slug and coffee insects. Among previously reported minor insects, coffee berry moth (Prophantis smaragdina) was the most commonly and frequently detected insect with mean proportion of 49.00and 34.84% in plantation and semi plantation coffee, respectively during wet season. Besides, coffee berry borer (Hypothenemus hampei) was again the most frequently detected pest on left over berries with average infestation of 27.80 and 52.88% during wet and dry season, respectively under plantation systems. Among berry feeding, scales insects and snails; Antestia bugs (Antestiopsis spp), berry moth, berry borer, halmet scale (Saisettia coffeae) and medium snails were negatively and coffee green scale (Coccus alpinus) and mussel scale (Lepidosaphes beckii) was positively associated with shade intensities. Most of coffee insect pests, slug and snails decreased as an altitudinal gradients increased except mealybugs, green and mussel scale which were positively related with altitude. This may implying the effect of shade and altitude variation depending on coffee insect species. Maintaining shade levels between 30-50% can be used as cultural insect pest's management options, but it depends on altitude, insect species, shade types and season. In combination with other management options, parasitoids can help to reduce pest damage due to coffee blotch miner. Identification of parasitoids is recommended for further study.

Key words: Coffee insect; Parasitism rate; Parasitized larvae; Season; Slugs; Snails

1 INTRODUCTION

There are different types of coffee in the world. Among these, the major economic species are *Coffea arabica* L. and *C. canephora* var. *robusta* Pierre ex A. Froehner. *Coffea arabica* L. is the most widely cultivated coffee species in the world, which accounts for about 58.68% of world coffee production (USDA, 2018). More than 125 million people worldwide are deriving their income directly or indirectly from its products in cultivation, processing, trading, transportation and marketing (Lashermes *et al.*, 2011; Mishra and Slater, 2012). Globally, *C. arabica* production is about 104,431thousand 60 kg bags in 2018 (ICO, 2019), and that of African countries is around 18,212 thousand 60kg bags (ICO, 2019). Whereas, the estimated annual national production of coffee in Ethiopia is about 7, 500 thousand of 60 kg bags (ICO, 2019).

In Ethiopia, the coffee is important to the economy of the country which is used as source of foreign income and also millions of the population relying on coffee production for their livelihood (ECTA, 2018). Nationally, it is estimated that there are around 5,270,777 households participated in coffee production activities (ECTA, 2018). However, an estimated over 25 million people are engaged at least on coffee production, distribution, trading, processing, exporting and other support and downstream activities (ECTA, 2018). It also accounts for 25-30 % of Ethiopia's total export earnings, 5% of the gross domestic product (GDP) and about 50% of the total production for domestic consumption(ECTA, 2018). The estimated annual national production of coffee in Ethiopia was about 619 kg ha^{-1} (CSA, 2018). The average national production is very low as compared to other major coffee producing countries.

Insect pests are one of the biotic factors that contribute to low yield (Million, 2000). Over 49 species of insect pests were recorded on coffee in Ethiopia, which were categorized as major, potential and minor pests (Million 1987; Esayas *et al.*, 2006). Among these, the Antestia bugs (*Antestiopsis intricata* and *A. facetoides*) and coffee blotch miner (*Leucoptera caffeina*) is major ones and coffee berry borer (*Hypothenemus hampei*), coffee thrips (*Diarthrothrips coffeae*), green scale (*Coccus alpinus*) and coffee cushion scale (*Stictococcus formicarius*) are potentially important coffee insect pests. The rest, over 85% of recorded coffee insect pests in Ethiopia is considered as minor and cause low damage. Nevertheless, it has been observed minor and potential pests, they may cause very serious damage. If however, there is any change in agronomic practices, natural biological balance (Crowe and Tadesse, 1984), and change in climate (Kambrekar *et al.,* 2015), those minor coffee insect pests could be increased in their status and become economically important pests to coffee. So, the study on status and dynamics of major and minor coffee insect pests should be important along different management gradient.

Due to current climate change and the shift from traditional to modern (intensive) farming systems, there might be increases in the distribution and abundance of minor insect pests, which need updated information. Some small animals like snails and slug became important, which were not commonly known as coffee pests in Ethiopia. These were observed on coffee leaves, green berries and stems during rainy season. Until recently, slug and snails are not common in coffee and are not considered as a problem. But, currently those small animals are commonly observed on coffee during rainy season, especially in plantation farms at Gomma, and growers are requesting its management options. In order to recommend its management it is necessary to consider the distribution and occurrences in different production systems, under shade level and altitudinal gradients that could be documented as baseline information.

Insect pests cause up to 20% of crop loss and reduce coffee value by 30 to 40% (Pablo *et al.*, 2012). A report on the major coffee insect pest in Ethiopia using artificial infestation with Antestia bugs showed that four pairs of the pest on branch caused 54% berry drop and 90% damaged berries (Mekasha, 2008). Earlier different pesticides have been evaluated and recommended for control of insect pests of coffee in Ethiopia (Crowe and Tadesse, 1984; Mekasha, 1993). Different agro ecologies (low, mid and high altitudes) and various coffee production types, and shade trees (as agroforestry system) in Ethiopia are opportunities for successful development of ecological insect pests management strategies.

Biological control is one method of pesticide free pest management option that uses living organisms (parasitoids, predators and pathogens), to reduce the coffee pest damage through different approaches. Beneficial insects (parasitoids) are among the most important natural enemies of coffee blotch miner and can contribute as one component of IPM. The diversity and abundance of beneficial insects (e g, pollinators) may decline in intensive agriculture (Briggs *et al.*, 2013), and also the higher abundance of natural enemies over the season was reported in unmanaged areas compared with organic production in blueberry agroecosystems (Whitehouse *et al.,* 2017).

Thus, knowledge on ecological aspects of insect pests and natural enemies in different coffee production systems is important for sustainable pest management and conservation of natural enemies; this also magnifies the importance of biological pest control. In addition to biological control agents (parasitoids) shade tree regulation as cultural method in diversified coffee agro forestry is one aspect that can reduce the cost of control, the production loss and damage from insect pests to coffee.

Shade trees in coffee farming systems might be an important cultural insect pest control, and also one of the options for mitigation to current climate change (Lin, 2010; Avelino *et al.*, 2011). There are pests benefiting from high shade intensities (Jonsson *et al.,* 2014, 2015), while others are negatively affected (Pardee and Philpott, 2011). But any control method requires understanding of the pests bio-ecology and its interrelations within the production agro ecosystem (Liebig, 2017). In Ethiopia, damage level of major and some minor coffee insect pests has been assessed and reported in intensive coffee production systems and in few cases in forest coffee production systems (CPS). The assessment did not take into account the different coffee production systems, shade level and altitudes at same time, that may either positively or negatively influence coffee pests. But determining effects of shade on coffee insect pests, on some gastropods, and coffee blotch miner parasitoids in different coffee production systems, shade level and along altitudinal gradients is needed, to develop ecological pest control methods.

General objective

To determine influence of production system, shade level and altitude on coffee insect pests and blotch miner (*Leucoptera caffeina*) parasitoid at Gera-Gomma, Ethiopia

Specific objectives

- To examine the influence of production system, shade level and altitude on leaf damaging coffee insect pests.
- To determine how production system, shade level and altitude influence coffee blotch miner parasitoids.
- To determine the influence of production system, shade level and altitude on berry feeding, sucking insect pests and some gastropods.

2 LITERATURE REVIEW

2.1 Coffee Production Systems in Ethiopia

Arabica coffee grows over a wide range of agro-ecological zones and geographical regions in Ethiopia (Senbeta, 2006). Coffee production systems in Ethiopia is categorized into different types namely forest coffee (FC), semi managed forest coffee (SFC), garden coffee (GC) and plantation coffee based up on management level, vegetation, structural complexity, and agronomic practices (Woldetsadik and Kebede, 2000; Tadesse *et al*., 2002, Tadesse, 2003, Senbeta and Denich, 2006). Wiersum (2010) and Hundera *et al.* (2013) also distinguished in to five coffee production systems by adding semi plantation (systematically planted, but traditionally managed) coffee production system. The coffee production systems also varied in their canopy cover (%), trees per hectare, number of canopy tree species and coffee plants per hectare (Tadesse, 2015). There is a high density of trees, small trees and shrubs in forest coffee production system followed by semi forest coffee production system (Tadesse, 2015).

Forest coffee is found in southeastern and southwestern parts of the country (Tadesse, 2015).In forest coffee production system no management to improve coffee productivity, with little human intervention. The only management practice in the forest system is access clearing to allow movement in the forest during harvesting time (Tadesse *et al*, 2001). Coffee forests are also rich in diversity of birds, animals and other groups of mammals (Tadesse, 2015). Semi forest coffee (managed forest), the forest coffee system is converted to semi-managed forest coffee system through reduction of plant composition, diversity and density. This production system is predominant in the south and southwest parts of the country and accounts for about 35 % of the coffee production (Tesfu, 2012). Tadesse (2015) stated that this production system is dominant in southwester Ethiopia and in the Bale Mountains of southeastern Ethiopia. The above author indicated that in this system, small trees and shrubs competing with coffee are cleared. Clearing is twice a year, one before and another after harvesting season, before the main rainy season starts (Tadesse, 2015).

In garden coffee production, smallholder farmers grow garden coffee near their residences mainly in the southern and eastern parts of the country. Cultural practices such as weeding 2-3 times per year, fertilizing with farmyard manure and crop residue and hoeing are commonly practiced in this coffee production system (Tadesse, 2015). Plantation coffee considered as commercial coffee production system and differs from others in the planting stocks and agronomic practices, use improved coffee varieties, are planted in row, with some chemical applications for fertilizer and disease control (Tadesse, 2015).

Forest coffee, semi-managed forest coffee and garden coffee are considered as 'traditional' coffee production systems (Tadesse *et al*., 2001). The traditional production systems account for 90-95% of the production, while plantation may range 5-10% (Tadesse, 2015). The average national productivity of coffee has been estimated as 15 kg ha-1, 54 kg ha-1 and 650 kg ha-1 for forest, semi forest and garden coffee, respectively (Schmitt *et al.*, 2009) and moderate to high yield (450-850kg ha-1) in plantation coffee (Woldetsadik and Kebede, 2000). But, the average productivity is very low in all coffee production systems, the low national yield might be due to different coffee production constraints. Coffee insect pests are one of the coffee production constraints for high yield and quality coffee in different production systems with varying degree.

Coffee insect pest status under different coffee production systems: The percent incidence of some coffee insect pests has been reported under different coffee production systems, with varying damage level in the country. Million (1987) reported that insect pests problem was more pronounced in coffee plantation than other coffee production systems. This mainly due to differences in cultural practices associated with the newly planted cultivars, and also due to disturbance of natural bio-control balance (Million, 1987).Major coffee insect pest (Antestia bugs), decreased in plantation farm due to intensive cultural practices, such as regulation of shade tree and pruning of coffee trees that in plantation coffee can reduce the Antestia (Esayas *et al.*, 2008). In forest coffee production systems the damage percent ranged between 10 and 56% during rainy season by different leaf damaging insect species (Chemeda *et al.*, 2015). Eyasu *et al.* (2019) reported that highest percentage damage of coffee berry borer under plantation coffee than garden coffee.

2.2 Coffee Shade

Shade coffee can be grown using a range of management systems, from cultivation under a thick, complex shade canopy with several tree species to systems in which coffee is shaded by a few small trees, all of the same species or of a few species (Moguel and Toledo, 1999). Shade intensities varied among coffee production systems, and estimate to 84%, 40-60%, 30-40% and 30-40% canopy cover of forest, semi- forest, garden and plantation coffee, respectively (Tadesse, 2015).

In southwestern Ethiopia, Arabica coffee is being grown by small holder farmers in shaded coffee agro ecosystems, under the canopy of contiguous or fragmented natural forest (Sumnegard *et al.,* 2014). Shade is more essential to *C. arabica* since the growth of coffee is affected by high light intensity, high temperature and low soil moisture (Ashenafi *et al.*, 2014). Shade level influence the occurrence of coffee insect pests either increasing or decreasing with increasing shade level, and may be species specific (Karungi *et al.,* 2015).

The effectiveness of shade types for ecological services (for beneficial and crop pests) depends on the interactions with different management gradients and altitude (Cerda *et al.*, 2017). Also, Staver *et al.* (2001) stated that the optimum shade level for pest suppression differ with climate, altitude and soils which need selection of tree species arrangement and density.

There are pests benefiting from high shade intensities (Lopez-Bravo *et al.*, 2012; Jonsson *et al.,* 2014; 2015), while others are negatively affected (Pardee and Philpott, 2011). Studies on shade coffee have shown that a diversified and abundant canopy of shade trees enhances associated biodiversity of plants and animals, including insects and birds (Perfecto *et al.*, 2003). There is a high density of trees, small trees, and shrubs in forest coffee production systems (Tadesse, 2015). These coffee agro ecosystems have been recognized as important areas for biological diversity conservation owing to its complex vegetation structure and high plant diversity (Gordon *et al.*, 2007; Lozada *et al.*, 2007). The diversity in shade tree species comprising the shade systems influences coffee insect pest like black coffee twig borer (*Xylosandrus compactus*) infestation (Kagezi *et al.*, 2013b; Dahlqvist, 2016).

Teodoro *et al. (*2009) stated that management of vegetational diversity in agroecosystems is a potentially regulating factor of pest population dynamics and may affect developmental stages in different ways. For example, the numbers of adult coffee berry borers per study site were higher in simple-shade and complex-shade agroforests compared with abandoned coffee agroforests (Teodro *et al.,* 2009). Similarly, the above authors also stated that densities of coffee leaf miner larvae and densities of all developmental stages of red spider mites per study site were higher in simple-shade agro forests compared with complex-shade and abandoned coffee agro forests. Increasing vegetation biodiversity in agro ecosystems can reduce the impact of pests and diseases by; conservation of natural enemies and facilitation of their action against aerial pests, and by disruption of the spatial and temporal cycle (reviewed in Ratnadass *et al.,* 2012). Study on shade coffee on some insect pests showed that shade significantly lowered the severity of coffee insect pests like *H. hampei*, *D. coffeae* and *Leucoptera* spp. and higher infestation of *Antestia thunbergii* in shaded compared to unshaded coffee (Mugo *et al.,* 2013). Similarly, in Ethiopia, *Antestia intricata* is more serious pest in shaded coffee at low altitude (Million, 1987).

2.3 The relationships between altitude and coffee insect pests

In addition to shade canopy level the effect of altitude on coffee insect pests remains controversial and might be insect group and other environmental factors (season) dependent. Different authors also indicated that coffee grown in low altitude was severely affected by coffee insect pests than at higher altitude (Le Pelley, 1968). For example, the highest proportion of damaged berries on dried leftover berries by coffee berry borer at low-altitude (Eyasu *et al.*, 2019), and also coffee berry moth, leaf miner and green scale was higher at low altitude as compared to high and mid altitude (Liebig, 2017). Antestia is more serious pest in shaded coffee at low altitude (Million, 1987). In contrast, there are coffee insect pests such as Antestia bugs population density and damage level increased as altitude increased (Ahmed *et al.*, 2016; Belay *et al.*, 2018).

The mean incidence of coffee blotch miner (*L. caffeina)* per 40 coffee trees at low altitude (~995m.a.s.l.) was ranged from 15.56 to 75.15 at Bebeka plantation coffee. Also, in same growing season the mean incidence of this insect pest at mid altitude (1485m.a.s.l.) per 50 coffee trees was estimated to 28.28 to 42.48 at Gomma II plantation coffee (Tamiru, unpublished data). From this the infestation of coffee blotch miner was higher at lower altitude than mid altitude in same coffee production system and its incidence depends on altitude. Study indicated that coffee stem borer infestation was higher in low altitude with different shade levels in intensive coffee production systems as compared to high altitude (Jonsson *et al.*, 2015).

2.4 Biology of major coffee insect pests in Ethiopia

Out of 49 coffee insect species reported in Ethiopia, the most important being Antestia bugs, coffee blotch miner and coffee berry borer. The basic biology of Antestia bugs, blotch miner and coffee berry borer is discussed below.

2.4.1 Biology of Antestia bugs, *Antestiopsis intricata*

Eggs are mostly laid on the underside of leaves usually in cluster of 12.Both at field and laboratory the *Antestiopsis* spp egg on the nylon cloth and underside of the coffee leaves are bounded to the support by glue excreted by the female during oviposition (Fig. 1).Under laboratory condition, the egg stage ranges from 3 to 5 days an average of 3.6 days (Million, 1987).In other study, incubation period ranged from 6 to 8 days, with average of 7.4 days was reported (Esayas and Million, 2004).*A. intricata* has five instars, the developmental stage ranged from 6-8, 9-13, 7-10, 6-14 and 7-14 with an average of 6.6, 10.3, 7.5, 8.8, 9.7 for 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} instras, respectively (Esayas and Million, 2004). The above authors also reported that the life span of 187+7.8 and 135 ± 10 days for the female and male insects, respectively.

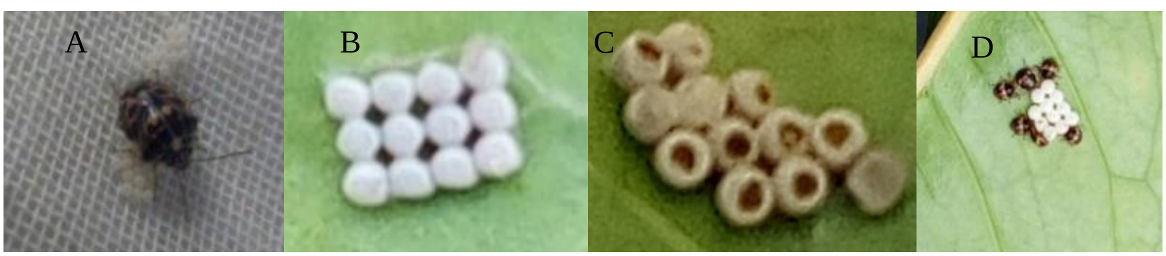

Figure 2. *Antestiopsis intricata*. Adult, eggs and nympal stages. A, *A. intricata* lay egg on nylon cloth (JARC entomology laboratory, 2017); B, un hatched egg masses of antestia bugs on coffee leaves bounded by glue excreted by female adult during oviposition; C, hatched eggs of Antestia bug; D, nympal stage of *A. intricata* after hatched. Eggs and immature stages are from Gomma-Gera coffee farms, 2019(Images A-D by Tamiru S.)

2.4.2 Biology of coffee blotch miners, *Leucoptera* spp

In Ethiopia, there are two species (*L. caffeina* Washbourn and *L. meyricki* Ghesquiere) of coffee blotch miner attacking coffee leaves (Million, 1987).Eggs are laid on the upper surface of the leaf by a small white moth, either is a straight line (L. *caffeina)* or in a group of 5 - 8 *(L. meyricki)*. When the larvae hatches it feed inside a leaf just below the upper epidermis (Fig. 2A and B) resulting in leaf damage (Crowe and Tadesse, 1984). Pupation takes place either on the tree or on fallen leaf (Crowe and Tadesse, 1984). During assessment, pupation takes place mostly on coffee trees on underside of the leaf (Fig. 2B) and in rare cases on the upper side of the coffee leaf (Fig. 2C). Crowe and Tadesse (1984) reported that the larval, pupal and adult stage range from 20–34 days, 7–14 days and 14 days (for the female), respectively.

Figure 3. *Leucoptera caffeina.* Mined leaf, white larvae, pupae and adult. A. *L. caffeina* hatched larvae feed inside a leaf below the upper epidermis; B,*L. caffeina* larvae white in color; C, pupation underside of coffee leaf; D, pupation upper side of leaf and E, Adult blotch miner moths. Images A-D are from Gomma-Gera coffee farms and E from JARC entomology laboratory, 2019 emerged from collected larvae from Gomma-Gera coffee fields (Images A-E by Tamiru S.)

2.4.3 Biology of coffee berry borer, *Hypothenemus hampei (*Ferriere)

The complete development period i.e. egg to adult took 24 to 43 days (31.7$\pm$0.8) (Esayas *et al.* (2005). Incubation period of egg, average developmental period of the larvae, and pupal period ranged from 5-10 days, 17$\pm$ 0.5 days, 5 to 9 days, respectively (Esayas *et al.,* 2005). Oviposition started at about 7-12 days after the emergence of female borer and it lays on average 2 eggs per day and a total of 32eggs on average (Esayas *et al.,* 2005).

2.5 The damage level and status of coffee insect pests in Ethiopia

Out of 49 coffee insect species reported in Ethiopia (Million 1987; Esayas *et al.*, 2006) coffee blotch miner (*Leucoptera caffeina*) and Antestia bugs (*Antestiopsis intricata* and *A. facetoides)* has been reported as major coffee insect pests in the country (Million and Bayisa, 1986; Million, 1987, 2000). Different authors also indicated that coffee in southwest Ethiopia is attacked by various leaf damaging insect pests (Fuad, 2010; Samnegard *et al.,* 2014; Chemeda *et al.,* 2015, Tamiru *et al.,* 2017), on berry feeding insects or coffee berry moth (Esayas and Abush, 2009; Chemeda *et al.*, 2011), coffee berry borer (EARO, 2000; Esayas *et al.,* 2004; 2008; Fuad, 2010; Chemeda *et al.,* 2011; Eyasu *et al.,* 2019) and on coffee fruit flies (Chemeda *et al*., 2011; Samnegard *et al.,* 2014), on Antestia bugs (Million, 1988; IAR, 1996b; Mekuria *et al*., 1993; Mekasha, 2008; Tamiru *et al.,* 2017, Belay *et al.,* 2018) and on coffee thrips (Negasu, *et al.,* 2017; Tamiru and Desalegn, 2018), with varying infestation level in the country, presumably because of different management gradients (shade status, production type, altitude and natural enemies). Climatic factors might also vary damage level and abundance of the insect pests.

Coffee leaf miners are one of the coffee insect pests damaging coffee leaf in Ethiopia and in other coffee growing areas, with different leaf miners species being dominant in different areas. The coffee leaf miner affects the coffee tree in various ways (Pereira *et al.,* 2007): the tree will not live long, there is a drop in the yield of the plant, and the quality of the coffee beans themselves is much reduced (Pereira *et al.,* 2007). Coffee blotch leaf miner, *Leucoptera caffeina* is one of the major coffee insect pests damaging coffee leaf in Ethiopia. Esayas and Chemeda (2007) reported a 4.4% mean infestation on artificially infested coffee seedlings, and 52.1% average infestation was recorded on naturally infested coffee seedling at Melko (Tamiru *et al.,* 2017).

Besides, other leaf damaging insect pests like serpentine leaf miner, coffee leaf skeletonizer (Fuad, 2010; Samnegard *et al.,* 2014; Chemeda *et al.,* 2015) was reported in southwestern Ethiopia, with different mean proportion. Fuad (2010) stated that the leaf damage proportion on wild coffee were 53%, 23% and 24% for leaf skeletonizer, serpentine and blotch leaf miner, respectively. The above author also stated the mean incidence of leaf damaging insects during wet (31.2%), transition (31.9%) and dry (17.62%) season, and the least was recorded during dry season. Similarly, in southwestern Ethiopia the abundance of coffee leaf skeletonizer, coffee blotch miners (*Leucoptera caffeina*/*L. meyricki*) and serpentine leaf miner (*Cryphiomystis aletreuta*) were found in 100, 88, and 71% of plots, respectively (Samnegard *et al.*, 2014). Also, the mean leaf damage of 2.7 to 31.76% by coffee leaf skeletonizer was recorded in southwestern and western coffee growing areas of Ethiopia (Tamiru *et al.,* 2017). In addition, other free feeding herbivore insect pests could also damage coffee leaves in Ethiopia. The mean leaf area loss due to herbivory was estimated between 3-17%, with average of 6.5% in southwestern Ethiopia (Samnegard *et al.*, 2014).

Due to current climate change (e.g. prolonged drought) some coffee insect pest/s (coffee thrips) which were considered as minor and potential pest become increased in distribution, population (density per coffee trees) and damage level. Coffee thrips is one of the drought dependent insect and defoliated the coffee leaves during prolonged drought in different coffee growing areas of Ethiopia (Tamiru and Desalegn, 2018). For example, the infestation of coffee thrips ranged from 5 to 50% in southern Ethiopia (Negasu *et al.,* 2017) and from 0.04 to 100% (Tamiru and Desalegn, 2018) in southwestern coffee growing areas of the country. Its damage level might depend on coffee production system, shade intensities, cultural practices used and season (was higher during dry spell).

Among berry feeding insect pests, coffee berry borer is one of coffee berry boring insect. The percent damage of coffee berry borer on dried leftover berries were determined by different authors; e.g., 13.3 - 61% (EARO, 2000); 4-60% (Esayas *et al.*, 2004); 8.48% (Chemeda *et al.*, 2011) and 37.5% (Eyasu *et al.,* 2019) in southwestern Ethiopia. Samnegard *et al. (*2014) also stated the percent incidence of fruit fly larvae in the ripe berries ranged from 0-85%, with average infestation of 58.8%.

Slug and snails in coffee plantation: In addition to coffee insect pests some small animals like slugs and snails are reported as coffee pests in some coffee growing countries, but not reported as serious pest in Ethiopia. The giant African snail *Achatina fulica* is a major crop pest that consumes over 500 plant species originated in East Africa and spreading across the globe primarily through human activities (Raut and Barker, 2002). A high incidence of the giant African snails was reported from the coffee areas of Araku valley zone in Visakha Agency and also some damage of coffee leaves was observed (Reddy and Sreedharan, 2006).

A small number of species are reported as serious pests of agriculture and horticulture crops this can eat coffee Arabica leaves during monsoon season (Anand and Geeta, 2017).Gastropod (snails and slug) are highly noticed on coffee trees (leaves, stem and berries) during rainy season in Ethiopia (e.g., in Jimma agricultural research field and Gomma coffee farm). But, its distribution along different management gradients is lacking in the country.

2.6 Management of Coffee Insect Pests

2.6.1 Cultural and Mechanical methods

From cultural insect pest control, pruning of coffee trees and shade tree regulation can reduce Antestia populations by producing unfavorable temperature and humidity conditions to Antestia bugs, which prefer dense foliage (Crowe and Tadesse, 1984).Cultural control of *Antestiopsis* spp. advocate to maintain coffee bushes open through regular pruning and hand collection can be successful on small plots of coffee (Enomoto, 2013; Mugo *et al.*, 2013).For blotch miner control hand squeezing larvae at the seedling stage (in green house, lath house and at nursery plot)is used, but not applicable at large scale farms. De la Mora *et al.* (2008) reported that shaded coffee agroecosystems have few pest problems due to higher abundance and diversity of predators of herbivores (like ants). The diversity and abundance of natural enemies of insect pests is often higher in agro-forestry plantations than in sun-exposed monocultures and used in biological pest control by improving pest suppression (Jonsson, 2015).

2.6.2 Botanical use

Milletia ferruginea (Hochest) Baker and *Chrysanthemum cinerariaefolium* L. induced 83.9 and 78.7 % adult mortalities, respectively (Esayas and Chemeda, 2007). *Chenopodium ambrosioides* and *Ekberga sp*. and *Myrsine Africana* significantly inhibited hatching of the Antestia bug eggs, indicating the ovicidal activity of the botanicals (Esayas and Chemeda, 2007).

2.6.3 Biological control

Bio–control agents are alternatives to the use of chemical pesticides and reduce the problem that has developed from the use of pesticides (Dhaliwal and Koul, 2007) to control pests.

Biological insect control is used in reducing the cost of control and its application for small scale farmer.

2.6.3.1 Parasitoids

Antestia bugs: About 45-50% Antestia eggs are attacked by three species of parasitoids (Million, 1987). Predominantly by *Asolcus suranus* Nixon followed by *Hadronotus antestiae* Dodd (Hymenoptera: Scelionidae) and *Anastatus antestiae* Ferriere (Hymenoptera: Eupelmidae) accounted for 33, 7 and 3 % of egg parasitization, respectively (Million, 1987). Also the above author reported only 5% of adults are attacked by 2 species of parasitoids namely, *Corioxenos antestiae* Blair and *Bogosia rubens* (Villeneave).

Blotch leaf miner: Blotch leaf miner was also attacked by eight species of parasitoids (Million and Bayissa, 1986; IAR, 1987), of which *Aphidencyrtus aphidivorus* and *Pediobius caffeicola* Ferr. were the most abundant species (IAR, 1987). Study conducted on the relative abundance of the parasitoids in Ethiopia indicated that from braconidae family, *Aphidencyrtus aphidivorus* was the most abundant species with 72.1 % and 54.2% parasitization at Melko and Agaro, respectively (Esayas *et al.*, 2011).

2.6.3.2 Entomopathogenic fungi

Entomopathogenic fungi are considered to play vital role as biological control agent of insect populations. The most common insect pathogenic fungi belong to the orders Entomophthorales and Hypocreales. These entomopathogens due to their eco-friendliness and bio-persistence are preferred to kill insects at various stages of its life cycle (Gul *et al*., 2014). In Ethiopia, the effectiveness of entomopathogenic fungi (*B. bassiana* and *M. ansopliae*) isolates was evaluated against some coffee insect pests (e.g., Antestia bugs and coffee berry borer) under laboratory condition.

As one element of biological control the effectiveness of entomopathogenic fungi isolates of *B. bassiana* and *M. ansopliae* were evaluated against Antestia bug (Belay, 2018). The isolates of *Beauvaria bassiana* (PPRC-27J and PPRC-44BC) showed promising results under laboratory condition (Belay, 2018). The above authors indicated that the higher concentration

($1x10^8$conidia per ml) showed complete mortality of the Antestia bug within short period of time relative to the lower concentrations. *Beauveria bassiana* showed 100% mortality on coffee berry borer and also killed within less or equal to 3.5 days of LT50 (Belay *et al.*, 2017).

2.6.4 Chemical control

Insecticides are essential tools in integrated pest management programs which can have the great influence if they are used properly, but the adverse impacts of these compounds on environment and ecosystem should not be ignored (Talebi *et al.*, 2011).In Ethiopia, different pesticides have been evaluated and recommended for control of major coffee insect pests. Mekasha (1993) recommended some insecticides i.e. Chlorpyrifos 48% EC (Dursban 4) 1.5L/ha, Cypermetrin (Nurelle D 25/360 EC) 1.125L/ha, Cypermetrin (Fenom 100 EC) 0.8L/ha, Fenitrothion (Sumithion 50% EC) 1.8L/ha for control of Antestia bugs when the average population of antestia (adult plus nymph) reaches more than 5 per coffee tree (Crowe and Tadesse, 1984). For control of coffee blotch miner fenitrothion at the rate of 2 ml of 50% EC in 1 liter of water when more than 30 moths flutter out from a single tree (Crowe and Tadesse, 1984). Besides to those major coffee insect pests insecticides were also recommended for minor coffee insect pests. Fenitrothion 50% E.C or fenthion 50% E.C for coffee leaf skeletonizer; dimethoate and thiometon for control of aphids, and fenitrothion should be carried out immediately and repeated after about 5-6 weeks for control of coffee berry moth (Crowe and Tadesse 1984).Pesticides alone will not solve the problem of controlling coffee insect pests. The significant consequences of use of pesticides are side effects on non-target organisms, sub-lethal effects of the pesticides on target and non-target organisms, emergence of resistant populations and pesticide residue and their entry into the trophic network (Talebi *et al.*, 2011).

3 MATERIALS AND METHODS

3.1 Description of the Study Areas

The study was carried out at Gomma-Gera districts (Table 1 & Fig. 3), in different coffee production systems (native forest to intensive production systems). Gomma-Gera was selected based on different production systems (forest from Gera and semi-forest, semi- plantation and plantation coffee from Gera-Gomma), and altitudinal gradients (high in Gera and low in Gomma). These two districts are found within Jimma zone, located in the southwestern part of Ethiopia, as described in Table 1.

The study was done for two seasons, i.e. in wet (July –August 2018) and dry season (January–March 2019) at Gomma-Gera southwest Ethiopia. Leaf miner parasitoids study was carried out during wet season of 2018 (July –August 2018). Preliminary identification of parasitoids (to family level) of coffee blotch miner was done at Jimma University College of Agriculture and Veterinary Medicine and Jimma Agricultural Research Center, Entomology laboratories based up on the morphological identification (wing structure, antennal segments, waist, size and color).

Table 1. Description of the study areas

Geographical information	**Study areas**	
	Gera	**Gomma**
Altitude (masl)	1390 to 2980	1387 to 2870
Latitude	7° 39' 59.99" N	7° 49' 59.99" N
Longitude	36° 14' 60.00" E	36° 39' 59.99" E
Mean annual rainfall (mm)	1878	1525
Mean annual max. temp (^{0}C)	24.4	29.9
Mean annual min. temp (^{0}C)	10.4	13.4

Source: https://latitude.to/map/et/ethiopia/cities/jima, JARC (Jimma Weather Station – 1,753m)

3.2 Experimental Procedures

A total of sixty experimental plots were selected from Gomma-Gera landscape (Fig. 3B). Within each plots, a 50×50m plot established, in which 16 coffee trees were selected on a grid in the innermost 30×30m with spacing of 10m between coffee trees. The selected coffee trees was marked (tagged) and assessed for damage by the different insect species. A total of 960 coffee trees from all selected plots were sampled.

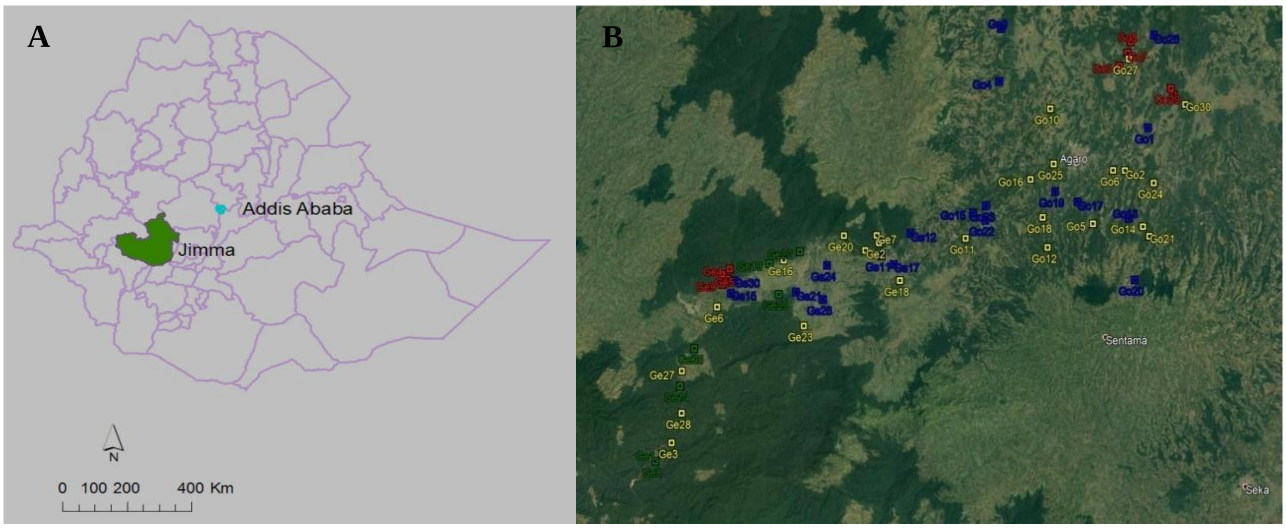

Figure 4. Location of study area. Panel A shows the Jimma zone (green) within Ethiopia. Panel B shows the sixty experimental plots, where the red, blue, yellow and green colors of the plot labels indicate the plantation, semi-plantation, semi-forest and forest coffee production system, respectively.

3.2.1 Assessment of coffee leaf damaging insect pests

For the leaf damaging insect pests (blotch and serpentine leaf miners, coffee leaf skeletonizer and other free feeding herbivores) two branches were randomly selected from each of the 16 trees per plot (a total of 1, 920 coffee branches from all selected plots were counted and assessed). The total number of leaves, as well as the number of damaged leaves was counted on both branches, the same branches was used for all species.

Leaf damaging insect pests recognized in the field based up on the damage symptoms observed on coffee leaf (blotch for *Leucoptera* spp; skeletonized leaf for coffee leaf skeletonizer and coffee leaf resembles a serpent (zig-zags through the leaf) for serpentine leaf miner. Coffee blotch miners (*Leucoptera caffeina/ L. meyricki*) recognized in the field based up on their eggs arrangement on the leaf. *Leucoptera caffeina* locates its eggs in net rows. In contrast, *L. meyricki* disperses its eggs on the leaf surface and identified by using hand lens in the field. To determine the percent infestation of those insect pests in different management gradients, incidence was calculated by using the equation;

$$\text{Incidence} = \frac{\text{Number of affected plant units}}{\text{Total number of plant units (healthy+affected plant units counted)}} \times 100$$

3.2.2 Assessment of berry feeding, sucking insect pests and gastropods

For each of the sixty plots, the same sixteen trees were examined for sign and symptoms of the coffee pests and gastropods by assessing the presence or absence of the coffee insect pests at the tree level. The sign (pests themselves observed on coffee tree) of sucking insects such as scale insects, Antestia bugs (both nymphs and adults), whitefly, coffee thrips, aphids and mealybugs were assessed at the tree level. In addition to sucking insect pests other non-hexapods such as red spider mite, slug and snails were recorded by using pictorial insects, slugs and snails identification guide. For berry feeding (coffee berry borer, berry moth, fruit flies), and stem borer insects both symptoms (damaged berries and stem) and signs (adult or larvae) was checked by dissecting the damaged coffee parts (berry and stem) on observed coffee tree.

3.3 Predictor Variables Measurement

3.3.1 Coffee production systems

The classification of sites into forest, semi-forest, semi plantation and plantation coffee production system was based on Senbeta and Denich (2006); Wiersum (2010); Hundera *et al.* (2013) and Tadesse (2015).

3.3.2 Shade level (%)

Shade canopy level was measured by taking pictures of the shade tree canopy from the ground. A photo was taken at five points in each plot. The percentage canopy cover was calculated for each photo using ImageJ image processing software (Rueden *et al.*, 2017), and an average of the five images were calculated for each plot and the study was included shade level between 13 to 83%.

3.3.3 Altitudinal gradient

The altitude (elevation) of each coffee plots were recorded using a handheld Global Positioning System (GPS) and the study was included an altitude range of 1506 to 2159m.a.s.l.

3.4 Coffee Blotch Miner (*Leucoptera caffeina*) Parasitoids

From each of the four coffee production systems (forest, semi-forest, semi-plantation and plantation coffee systems),a total of sixteen plots were assessed and 100 leaves per plot mined by the coffee blotch miner was collected in plastic bags. To increase the rearing success, only leaves with undamaged and middle or large mine surface was selected. The mined leaves were collected in plastic bags in the field and the plot ID was kept track of during the collection phase and during the lab rearing. All collected leaves infested by coffee blotch leaf miner were stored in a plastic box with 6cm height and 24.5cm length (147cm^2 area), in sets of 2-3 leaves per box. Tissue paper (two sheets of toilet paper) was added to the plastic box to absorb the moisture and prevent the fungal growth.

The white plastic boxes with area 147cm^2were regularly inspected for any signs of emerged moths and their parasitoids, and larval parasitized. The emerged parasitoids and adult moths and parasitized larvae were placed on a white paper and sorted after 25-35 days(Fig. 4, Appendix Fig. 1&2). The number of days is based on the biology of blotch leaf miner studied: Crowe and Tadesse (1984) reported that the larval, pupal and adult stage range from 20–34 days, 7–14 days and 14 days (for the female), respectively. The number of blotch miner adults and parasitoids emerged and parasitism rate was recorded. The parasitism rate was determined by the following formulae:

$$\text{Parasitism rate} = \frac{\text{The number of parasitoids emerged}}{\text{The number of blotch miner moths emerged}}$$

Emerged parasitoids were classified in to different taxonomical groups based on the morphological characteristics (size, color, antennal segments and waist and wing structure-preliminary identification) under the microscope to higher-level (family level) (Fig.4). After this, the emerged parasitoids were stored in tubes with ethanol 97% for further study.

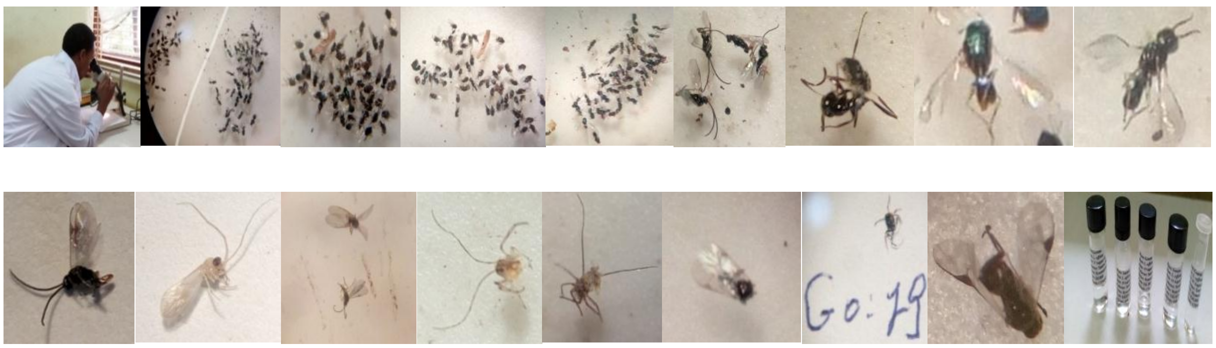

Figure 5. Morphological based classification of emerged coffee blotch miner parasitoids under microscope and stored in tubes in JUCAVM and JARC laboratories, 2018/2019

3.5 Statistical Analysis

A generalized linear mixed model (GLMMs) was used to examine the influence of production systems, shade level and altitude on leaf damaging insect pests and parasitoid abundance. Generalized linear model (GLM) with binomial family, logit link function was used for presence/absence insect data in R software. The R software (R Studio Version 3.5.3, R Core Team, 2019) was used for the analyses. The analysis of variance (ANOVA) function in the car package was used to obtain ANOVA tables. Abline function was used to add straight line (to draw regression lines), in relationships between shade and insect pests, and altitude and insect pests. Pearson correlation coefficient was used to determine the relationship between variables.

4 RESULTS AND DISCUSSION

4.1 Influence of Production System, Shade Level and Altitude on Leaf Damaging Insects

The results showed that production system, shade level and altitude had highly significant influence (P=8.0e-05, P= 0.009 and P=7.4e-12, respectively) on coffee blotch miner during wet season of 2018, while no significant effect was observed during the dry season of 2019 (Table 2). Increase in an altitude and shade canopy closure significantly decreased the coffee blotch miner abundance. Similarly, altitude and coffee production system had a significant effect on coffee leaf skeletonizer, serpentine leaf miner and free feeding herbivore in wet season (Table 2, Fig. 5& Fig. 6). However, in the dry season only serpentine leaf miner and coffee leaf skeletonizer had significantly influenced by shade level and altitude, respectively (Table 2). Both during wet and dry seasons the abundance of leaf damaging insect pests were decreased with altitude increased (Fig.6A-E).

Table 2.The influence of production system, shade and altitude on leaf damaging insect pests at Gomma-Gera, southwest Ethiopia in 2018/2019. The bold numbers and the ± signs in the bracket shows the significant value at 5% probability level and direction of the response, respectively

Leaf damaging insects	Production system		Shade (%)		Altitude(m.a.s.l.)	
	Seasons (2018/2019)					
	Wet	Dry	Wet	Dry	Wet	Dry
Leucoptera caffeina	**8.0e-05**	0.73	**0.009 (-)**	0.13(-)	**7.4e-12** (-)	0.31(-)
Leucoptera meyricki	0.72	-	0.16(+)	-	0.48(+)	-
Cryphiomystis aletreut	**0.004**	0.25	0.63(+)	**0.03(-)**	**0.007(-)**	0.08(-)
Leucoplema doherty	**0.0003**	0.30	0.23(+)	0.21(-)	**0.006(-)**	**0.0002(-)**
Free feeding herbivore	**8.83e-05**	0.92	0.26(+)	0.55(+)	**0.0006(-)**	0.09(+)

Coffee production systems influence the leaf damaging insect pests: A production system was the predictor variable shown to influence coffee leaf feeding insect pest abundance (Fig. 5A-D). In wet season, the mean proportion of coffee blotch miner, serpentine leaf miner, coffee leaf skeletonizer and free feeding herbivores varied from 0-56%, 0-5%, 4-84%, 7-84%, respectively (Fig.5A-D) under different coffee production system.

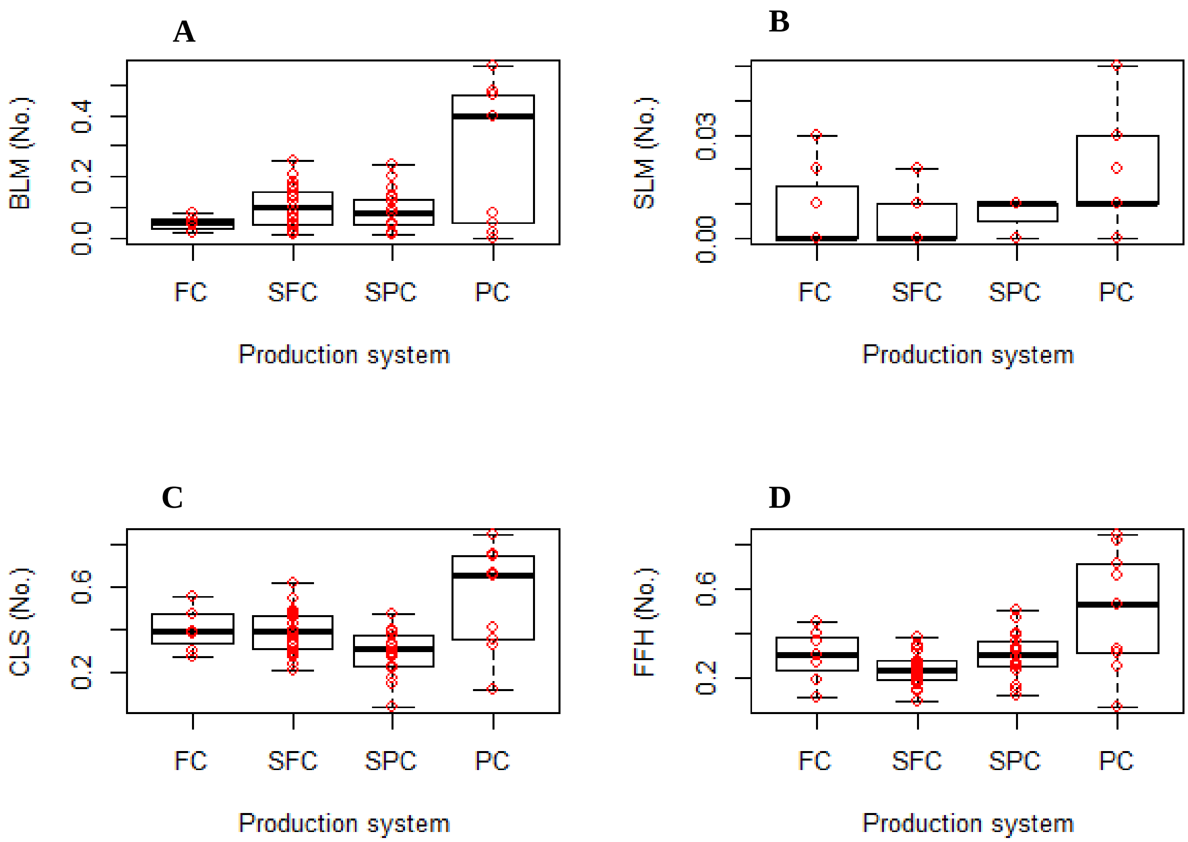

Figure 6. Influence of coffee production system on leaf damaging insect pests in wet season of 2018/2019 at Gomma-Gera, southwest Ethiopia. (BLM: blotch miner; SLM: serpentine leaf miner; CLS: coffee leaf skeletonizer and FFH: free feeding herbivore. FC: Forest Coffee; SFC: Semi Forest Coffee; SPC: Semi Plantation Coffee and PC: Plantation Coffee

As results, the mean proportions of coffee insect pests (leaf damaging) were highest in plantation coffee as compared to the rest coffee production systems and increase intensification significantly increased the damage caused by leaf damaging insect pests. In forest coffee production systems the insect pest's damage was very low, this might be due to natural enemies (e.g., blotch miner parasitoids that addressed in section 4.3) abundantly found in unmanaged (forest) coffee ecosystem. In this coffee production systems there is a high density of small trees and shrubs (Tadesse *et al.*, 2015), and probably important for bio agent conservation and enhancing their activities. Generally, all assessed coffee insect pests (coffee blotch miner, serpentine leaf miner, coffee leaf skeletonizer and free feeding herbivore) were abundantly found in plantation coffee with varied intensity. This result agreed with Million (1987) that reported pest problems are more problematic in intensive coffee production system than garden and semi forest.

Leaf damaging insect pests were abundantly found in all coffee production systems (forest, semi forest, semi plantation and plantation CPS) with varied degree and abundantly found during wet season than dry season. Similarly, Chemeda *et al.* (2015) stated that the highest incidence 33.06% of leaf damaging coffee insect pests in forest coffee, when the amount of rainfall was very high compared to other seasons. Fuad (2010) also stated that mean incidence of leaf damaging insects (coffee leaf skeletonizer, serpentine and blotch leaf miner) was higher during transition (31.9%) and wet (31.2%) as compared to dry (17.62%) season. Samnegard *et al.* (2014) reported that coffee leaf skeletonizer, coffee blotch miner (*Leucoptera caffeina* / *L. meyricki*) and serpentine leaf miner was present in 100%, 88% and 71% of plots, respectively.

Coffee blotch miner comes after coffee leaf skeletonizer and free feeding herbivore in terms of its percent incidence in all coffee production system. However, Million and Bayisa (1986); Million (1987; 2000) reported that coffee blotch miner comes next to Antestia bug in economic importance. But, based up on this result the intensity was lower than coffee leaf skeletonizer in all coffee production systems during both seasons (dry and wet). Similarly, Chemeda *et al.* (2015) reported lowest proportional incidence among leaf damaging insect pests across forest coffee production. This lower percent incidence of coffee blotch miner than coffee leaf skeletonizer might be due to the abundance and diversity of coffee blotch miner parasitoids and other natural enemies, and the current weather variables might be favorable for this minor (coffee leaf skeletonizer) insect pest damage.

Coffee leaf skeletonizer was commonly and frequently observed during both seasons in all coffee production systems. The mean proportion ranged from 7-84% and 18-60% during wet and dry season, respectively. This indicated there were no coffee trees free from this insect pest attack in all production systems except in semi plantation coffee (Fig. 5C). Different authors (e.g., Fuad, 2010; Samnegard *et al.*, 2014; Chemeda *et al.*, 2015) reported that coffee leaf skeletonizer ranked first in percent incidence as compare to other leaf damaging insect pests (coffee blotch leaf miner/s, serpentine miner). Million and Bayisa (1986); Million (1987,

2000) stated that coffee leaf skeletonizer considered as minor pest in Ethiopia. However, coffee leaf skeletonizer ranked first in percent incidence among all commonly occurring coffee leaf damaging insect pests in forest coffee production systems (Chemeda *et al.*, 2015).

Serpentine miner was also one of the pests influenced by coffee production systems with mean proportion ranged from 0-5% and 0-22.0% during wet and dry season, respectively. The leaf damage proportion of serpentine leaf miner was estimated to 23% on wild coffee (Fuad, 2010), and was found in 71% of plots (Samnegard *et al.*, 2014). Chemeda *et al.* (2015) also ranked second in percent incidence among all commonly occurring coffee leaf damaging insect pests in forest coffee.

Free feeding herbivores were other coffee pests infesting the coffee leaf during field assessment. During wet season the highest mean proportion of free feeding herbivores insect pest was recorded in plantation (84%) coffee followed by semi plantation (50%), forest (45%) and semi forest coffee (38%) (Fig.5D). However, production systems had no influence free feeding insect pests during dry season. Samnegard *et al.* (2014) also, estimated the mean leaf area loss due to herbivory was between 3-17%, with average of 6.5% in southwestern Ethiopia.

Influence of altitude and shade level on leaf damaging coffee insect pests: During wet season all of the assessed leaf damaging coffee insect pests significantly influenced by altitudinal gradients and decreased as altitude increased except for *Leucoptera meyricki* (Table 2, Fig. 6A-E). However, during dry season only coffee leaf skeletonizer was significantly influenced by altitude. Leaf damaging insect pests were negatively correlated with altitude during both seasons (Appendix Table 1).Coffee blotch miner during wet season and serpentine leaf miner during dry season decreased as shade level increased and negatively associated with shade intensities (Fig. 6F & G).

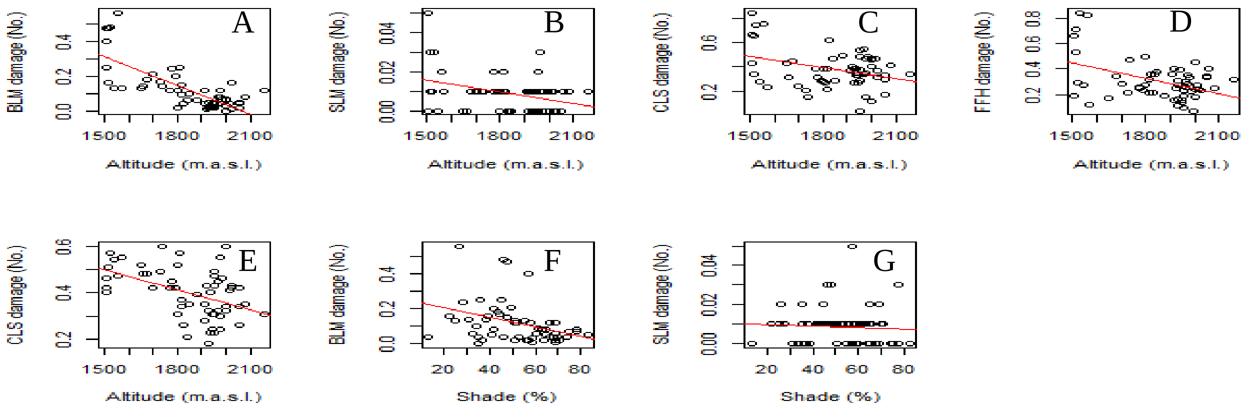

Figure 7. Effects of altitude on leaf damaging insects in wet (A-D) and dry season (E) of 2018/2019 at Gomma-Gera, southwest Ethiopia. BLM: blotch leaf miner; SLM: serpentine leaf miner; CLS: coffee leaf skeletonizer and FFH: free feeding herbivore

The result showed that leaf damaging coffee insect pests decreased as altitude increased and negatively affected the insect abundance during both wet and dry seasons, and similar reports has been found in other studies as well; coffee grown in low altitude was severely affected than at higher altitude (Le Pelley, 1968). Liebig (2017) also stated that some coffee insect pests like coffee berry moth, leaf miner and green scale occurrence was lowered at higher altitude compared to low and mid altitude. And also other study on other coffee insect pests contradicted with these results, which were discussed under section of 4.3 (influence of altitude on berry feeding, sucking insects, slug and snails). However, the effect of altitude on coffee insect pests remains controversial and depends on insect group (species), production systems and weather variables (season).

Shade effects on coffee insect pests: coffee blotch miner and serpentine leaf miner decreased as shade intensities increased. Similar reports that has been found in other studies showed that shade significantly lowered the severity of coffee insect pests like coffee blotch miners (*Leucoptera* spp), coffee berry borer (*H. hampei*) and coffee thrips (*D. coffeae*) (Mugo *et al.*,2013). However, there are conflicting reports on influence of shade on coffee insect pests that was negatively affected by high shade intensities (Pardee and Philpott, 2011) or increased as shade intensities increased (Jonsson *et al.*, 2014; 2015). These different reports could depend on coffee insect species and other environmental variables.

4.2 Influence of Coffee Production System, Shade Level and Altitude on Coffee Blotch Miner Parasitoids

Coffee production system was significantly influenced the number of emerged blotch miner adult and its parasitoids (Table 3, Fig. 7). Higher number of parasitoids was emerged under semi forest coffee production systems (Fig.7A). Shade level had no effect on parasitoids and adult blotch miner moth (Table 3). Altitude had showed a significant effect on adult blotch miner moth and parasitized larvae. Among emerged parasitoids Euluphidae parasitoid and parasitized larvae was significantly influenced by altitudinal gradient. Parasitized larvae were positively correlated with altitude (Appendix Table 3). Adult blotch miner moth decreased with altitude while parasitized larvae increased with altitude (Fig. 8A-C).

Table 3. Influence of coffee production system, shade level and altitude on coffee blotch miner parasitoids and blotch miner adult moth at Gomma-Gera, southwest Ethiopia in 2018/2019. The bold numbers and the ± signs in the brackets after the P-values shows the probability level at 5% and direction of the response, respectively

Response variables (No.)	**Production system**	**Shade (%)**	**Altitude(m.a.s.l.)**
Parasitoids emerged	**0.02**	0.37(-)	0.91(-)
Adult blotch miner emerged	**2.53e-06**	0.21(-)	**0.0004 (-)**
Parasitized larvae	0.18	0.51(-)	**0.023 (+)**
Parasitism rate	0.23	0.87(-)	0.22(+)
Apanteles spp.	0.19	0.71(+)	0.23 (+)
Braconidae	0.078	0.22(+)	0.07(+)
Encyrtidae	0.27	0.84(+)	0.22(+)
Eulophidae	**0.007**	0.76(+)	**0.001(+)**
Ichneumonoidae	0.10	0.93(-)	0.13(+)
Others	0.28	0.97(+)	0.33(+)

Influence of coffee production system on coffee blotch miner parasitoids: Coffee production system influence the abundance of parasitoids and blotch miner adult moth (Fig. 7A-C), with highest emerged parasitoids in semi forest coffee (51.69%), followed by semi plantation (45.54%) and plantation coffee (6.40%) in total population. However, the emerged blotch miner adult was highest in plantation (69.00%) followed, semi forest

(18.26%) and semi plantation coffee (12.74 %).Among emerged parasitoids family Eulophidae was highest in semi plantation coffee followed by semi forest and semi plantation (Fig.7B).

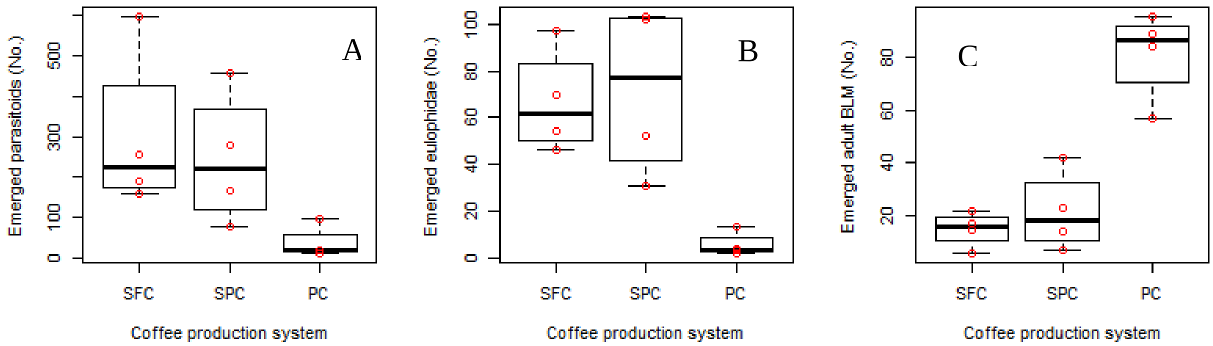

Figure 8. Influence of coffee production system on emerged number of total parasitoids (A), Eulophidae parasitoid/s (B) and adult blotch miner moth (C) at Gomma-Gera, southwest Ethiopia in 2018/2019. SFC: Semi Forest Coffee; SPC: Semi Plantation Coffee and PC: Plantation Coffee

The mean numbers of coffee blotch miner parasitoids were significantly lowest in plantation coffee as compared to the rest coffee production systems. Another study on beneficial insects (i.e. pollinators) indicated that taxonomic richness of the flower visiting insects significantly decreased and pollinator community changed with increasing forest management and fragmentation (Gezahegn, 2014).Medeiros *et al.* (2019) also reported that over use of agrochemicals and expansions of monocultures have resulted in the loss of beneficial insects. The highest mean proportion was found in less managed (semi forest coffee) followed by semi plantation coffee (Fig.7A). This result supports the previous reports which suggested that the abundance of natural enemies was higher in garden and forest (Million, 1987; Esayas *et al.*, 2006); in agro forestry plantation (Jonsson *et al.*, 2014); and in unmanaged (Whitehouse *et al.*, 2017) than plantation, sun exposed and conventional production systems. This might be because of alternative food source (pollen and nectar), available for adult parasitoid under unmanaged coffee production than intensively managed coffee ecosystems. There is also no impact of chemicals such as herbicides in the forest system that affects natural enemies. The above authors and the result suggested that, while natural enemies of pests could be more abundant in unmanaged production systems and in diverse agro forestry. Such production systems could be more favorable for insect pest natural enemies and at same time can used for biological insects control method.

From the three coffee production systems different coffee leaf miner hymenoptera parasitoid (grouped to encyrtids, eulophids, braconids and other parasitic hymenoptera) were emerged. Esayas *et al.* (2011) reported that from Braconidae family *Aphidencyrtus aphidiuorus* (54.2%) and Eulophidae *Pediobius coffeicola* (33.0%) were the most abundant species of coffee blotch miner larval parasitoids at Agaro. Also, among eight species of parasitoids attacked coffee blotch miner reported (Million and Bayissa, 1986; IAR, 1987), *Aphidencyrtus aphidivorus* and *Pediobius caffeicola* Ferr. were the most abundant species (IAR, 1987).

Effects of altitude on emerged parasitoids, parasitized larvae and adult blotch leaf miner: Eulophid/s parasitoids and parasitized larvae increased with altitude while coffee blotch miner adult moth decreased with altitude (Fig.8A-C). This study suggests that those emerged larvae parasitoids are effective in managing coffee blotch miner insect as a biological pest control, thereby confirming the lower mean infestation of this insect pest as compared to minor pest (coffee leaf skeletonizer and free feeding herbivore) discussed in section 4.1 (coffee production system influence the leaf damaging insect pests).

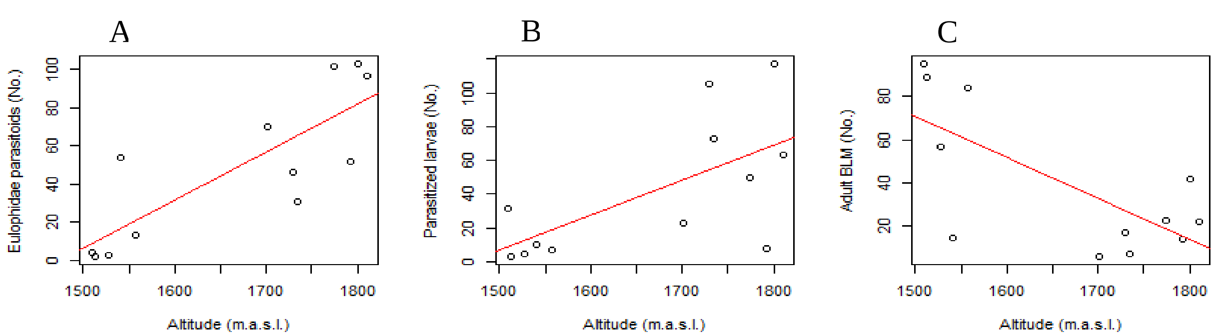

Figure 9. The effect of altitude on Eulophidae parasitoids (A), parasitized larvae (B) and adult blotch miner moth (BLM) (C)) at Gomma-Gera, southwest Ethiopia in 2018/2019

Overall, the coffee blotch miner adult was abundantly found in plantation coffee whereas, that of parasitoids was abundantly found under semi forest coffee production systems. This result agrees with the former study of Million (1987) who reported that pest problems are more problematic in intensive coffee production system than garden and semi forest. Also Medeiros *et al.* (2019) reported that over use of agrochemicals and expansions of monocultures have resulted in the loss of beneficial insects, which might be disturb the balance between the natural enemies and insect pest/s. No freshly mined leaves by coffee blotch miner were found in forest coffee production systems during data collection during wet season of 2018/2019, probably due to the fact that the parasitoids (plus other natural enemies) of these insect pest abundantly found in the forest systems. Similarly, Chemeda *et al.* (2015) reported that the lowest proportional incidence of coffee blotch miner among leaf damaging insect pests across forest coffee production systems. This might because of coffee blotch miner natural enemies (e.g. parasitoids) was abundantly found under forest coffee production resulted in reducing this insect damage.

Different authors also, reported that the abundance of natural enemies was higher in garden and forest (Million, 1987); in agro forestry plantation (Jonsson *et al.,* 2014); and in unmanaged (Whitehouse *et al.,* 2017) than plantation, sun exposed and conventional production systems. This might be in plantation coffee production systems different inputs (herbicides, fungicides for control of weeds and major diseases) used could reducing the abundance of coffee blotch miner parasitoids or might be due to the availability of food sources (pollen and nectar used as food sources for adult parasitoids) in forest coffee than plantation coffee. Also, in plantation systems growers usually growing genetically more uniform coffee genotypes (selections or hybrids), than other coffee productions systems (forest, semi forest, semi plantation and garden coffee), diversified types reducing pests and increasing the natural enemies of coffee pests. The more uniform coffee genotypes planted in plantation systems may favor the pest infestation than the diversified coffee systems, this because of the more diversified coffee farms might be affecting the special and life cycle of insect pests in addition by affecting the micro environmental condition (e.g. shade trees and other non-coffee tree densities in forest coffee than plantation coffee).

There were more moths emerged from collected freshly mined leaves in low altitude under plantation coffee (Fig. 7A). This result agrees with the recent study of Liebig (2017) who indicated that some coffee insect pests like leaf miner, coffee berry moth and green scale occurrence was lowered at higher altitude compared to low and mid altitude, probably due to the high vegetation at high altitude than low altitude favor their natural enemies or might be due to microclimates (temperature) decreased the pest abundance at high altitude. The coffee blotch miner adult moth emerged increased in low altitude under plantation coffee, and the parasitoids was found abundantly under semi forest and semi plantation than plantation coffee.

4.3 Influence of Coffee production system, Shade level and Altitude on Berry Feeding, Sucking Insect Pests and Some Gastropods

In addition to leaf damaging insect pests, other coffee insect pest namely: berry and seed attackers (coffee berry borer, berry moth and fruit flies); sucking insects (coffee aphids, black thread scale, coffee green scale, mussel scale, mealy bugs, Antestia bugs, coffee thrips, coffee white flies; ants (crematogaster, big black biting and driver ants); stem boring insect (stem borers), and some non-hexapods (red spider mite and gastropods (slugs and snails depends on the size)) were assessed and their abundance was analyzed in 2018/2019 with relation to coffee production systems, shade and altitude.

The assessment of insects and non-hexapod pest during wet season and dry season reveled, out of twenty two pests, seven insect pests and slug (from non-hexapod) were influenced by different coffee production systems (Table 4, Fig. 9A-H).From assessed insects and none hexapods six (during wet season) and two (during dry season) pests was influenced by coffee production systems. Similarly, in 2018/2019 nine insect pests and medium snail was influenced by shade level (Table 4, Fig. 10). Altitude was also another factor significantly influenced the pests. Among assessed pests; eight (wet season) and six (dry season) pests were affected by altitude (Table 4 & Fig. 11).

Table 4. The influence of production systems, shade level and altitude on berry feeding, sucking insect pests and some gastropods at Gomma-Gera, Ethiopia in 2018/2019. The bold numbers and the ± signs in the bracket show the significant value at 5% probability level and direction of the response, respectively

Coffee pests	**Production system**		**Shade level**		**Altitude**	
	Seasons (2018/2019)					
	Wet	**Dry**	**wet**	**Dry**	**Wet**	**Dry**
Antestia bugs	**0.005**	0.09	**0.004(-)**	**0.002(-)**	**1.44e-05(-)**	**0.003(-)**
Aphids	**0.005**	0.12	0.54(-)	0.06(-)	0.48(-)	0.75(+)
Black thread scale	0.35	**3.70e-05**	0.84(+)	0.99(+)	0.44(+)	0.96(+)
Halmet scale	**0.0009**	0.053	0.52(+)	**0.008**(-)	0.13(+)	0.19(-)
Green scale	0.23	0.06	**0.002(+)**	0.28(-)	**7.32e-05**(+)	0.38(+)
Mussel Scale	0.58	0.59	**0.05(+)**	0.22(+)	**3.27e-07**(+)	**0.0005**(+)
Mealy Bugs	0.89	0.60	0.18(+)	0.79(-)	**0.04**(+)	0.60(-)
Red spider mites	0.09	0.29	0.85(+)	0.11(+)	0.75(+)	0.51(+)
Coffee thrips	-	0.28	-	0.26(-)	-	**0.02**(-)
White fly	0.09	0.48	0.80(-)	0.17(+)	0.12(+)	0.36(+)
Stinging caterpillar	0.39	0.72	0.19(+)	0.64(-)	0.19(+)	0.78(-)
Coffee stem borer	0.88	-	0.24(+)	-	0.42(+)	-
Coffee berry moth	**0.003**	**-**	**0.009(-)**	-	0.49(-)	-
Coffee berry borer	**0.02**	**4.38e-07**	**0.0001(+)**	**0.01**(-)	**6.02e-05**(-)	0.13(-)
Coffee fruit flies	**-**	0.13	**-**	0.05(-)	**-**	0.07(-)
Crematogaster ants	0.98	0.12	0.42(+)	0.06(-)	0.58(+)	0.21(-)
Black biting ant	0.40	0.18	**0.002(-)**	0.46(-)	0.70(-)	**0.03**(-)
Driver ant	-	0.09	-	0.09(-)	-	0.07(-)
Slug	**3.5e-05**	0.12	0.17(-)	0.20(-)	**2.4e-05(-)**	**1.72e-05(-)**
Small snail	0.46	0.13	0.23(-)	0.79(-)	**3.58e-05(-)**	0.69(-)
Medium snail	0.32	0.56	0.07(-)	**0.001(-)**	**0.0006(-)**	**0.002(-)**
Other snails	0.83	-	0.22(-)	-	0.16(-)	**-**

4.3.1 Coffee production systems influence berry feeding, sucking insect pests and some gastropods

During wet and dry season of 2018/2019, around 18 coffee hexapods and 4 gastropods were assessed along different management gradients at Gomma-Gera of southwestern Ethiopia (Table 4). Out of those pests; Antestia bugs, aphid, berry moth, berry borer, halmet scale and from gastropod; slug was significantly influenced by coffee production system during wet season (Table 4, Fig. 9A-F). While only black thread scale (P=3.7e-05) and coffee berry borer, P=4.38e-07) were highly influenced by coffee production system during dry season (Table 4, Fig. 9G & H). Coffee pests were abundantly found in all assessed plots with varying degree both during rainy and dry season. In 2018/2019, the highest abundance of coffee insects and gastropods were recorded in the plantation coffee while the lowest was recorded in the forest coffee production systems (Fig. 9A-H).

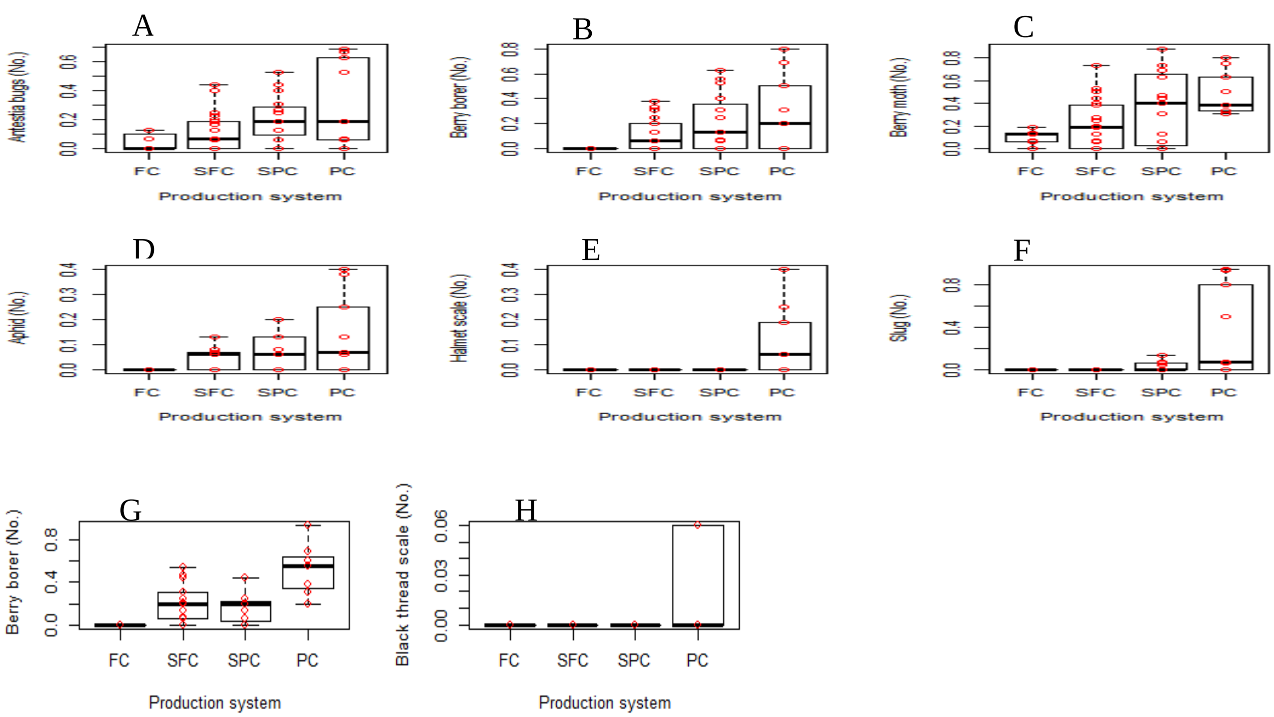

Figure 10. The influence of coffee production system on berry feeding, sucking insect pests and slug during wet season (A-F) and dry season (G and H) of 2018/2019 at Gomma-Gera, southwest Ethiopia. FC: Forest Coffee; SFC: Semi Forest Coffee and SPC: Semi Plantation Coffee; PC: Plantation Coffee.

The minimum and maximum percent pest incidence was ranged from 0-94%, under different coffee production systems. As compared to the four coffee production systems, the mean proportions of coffee insect pests were highest in plantation and lowest in forest coffee (Fig. 9). This could be due to the reason already described under coffee production systems influence leaf damaging insect pests. In general, the infestation of most coffee insect pests assessed at Gomma-Gera was lowest in forest coffee systems. Coffee berry moth was the most commonly and frequently detected insect pest with mean proportion of 49.00 (plantation) and 34.84 % (semi plantation coffee) during wet season (Fig. 9C). Coffee berry borer was again the most detected berry boring insect with mean proportion of 27.8 and 52.88% under PC during wet and dry season, respectively (Fig. 9G). From sucking insects coffee thrips was detected at levels ranging from nil to 45% during wet season and dry season, respectively under different coffee production systems and the highest was recorded under plantation coffee at low altitude (Gomma plots).

Most coffee pests such as Antestia bugs, berry moth, and other sucking insects were abundantly found during wet season as compared to dry season. However, coffee thrips and coffee berry borer was abundantly found during dry season. This might be due to the crop growth stage (bud formation, flowering, pinhead and expansion stages) suitable for its abundance. In general, the status (abundance) of some previously minor and potential pests such as coffee berry moth, coffee fruit fly, coffee thrips, coffee berry borer, slugs and snails increased and became economically important.

The maximum mean proportion of Antestia bugs were recorded in plantation as compared to other (forest, semi forest and semi plantation) coffee production systems. Antestia bug (*Antestiopsis intricata*) occurred as sporadic at Yayu and Berhane-Kontir forest coffee production system (Chemeda *et al.*, 2011). Esayas *et al.* (2008) reported that Antestia bugs decreased in plantation farm due to cultural practices, such as regulation of shade tree and pruning of coffee trees that are intensively practiced. Similar to Antestia bugs, the mean proportion of coffee aphid, berry moth, berry borer, halmet scale and slug were observed in plantation coffee (Fig. 9).

Coffee berry borer was observed both during wet and dry season in all coffee production systems (plantation, semi plantation and semi forest) except in forest coffee (Fig. 9). During dry period the infestation of this insect pest was increased twice under plantation as compared to wet season in same coffee production systems. Similarly, Eyasu *et al.* (2019) reported that highest percentage damage (24.51%) of coffee berry borer on dried leftover berries in plantation management system than garden coffee. On other hand, the lowest mean percent damage under forest coffee production system was observed during both seasons on leftover berries. Also, Chemeda *et al.* (2011) stated that relatively lower incidence of this insect pest (8.38%) on dried leftover berries in forest coffee production system. In Ethiopia, there are reports indicating the increment of coffee berry borer infestation, after the first incidence as reported by Davidson (1968) and currently by Eyasu *et al.* (2019) on left over berries with varied range of infestation in different coffee growing areas of the country.

4.3.2 Influence of shade level on berry feeding and sucking insects pests

From assessed coffee insect pests; Antestia bugs, green scale, mussel scale, berry moth, berry borer and black biting ant during wet season and Antestia bugs, halmet scale, berry borer and medium snail during dry season significantly influenced by shade intensities (Table 4), and decreased as shade canopy closure increased except green scale and mussel scale during wet season(Fig. 10). However, Antestia bugs, halmet scale and berry borer decreased as shade canopy closure increased during dry season (Fig. 10GHI).

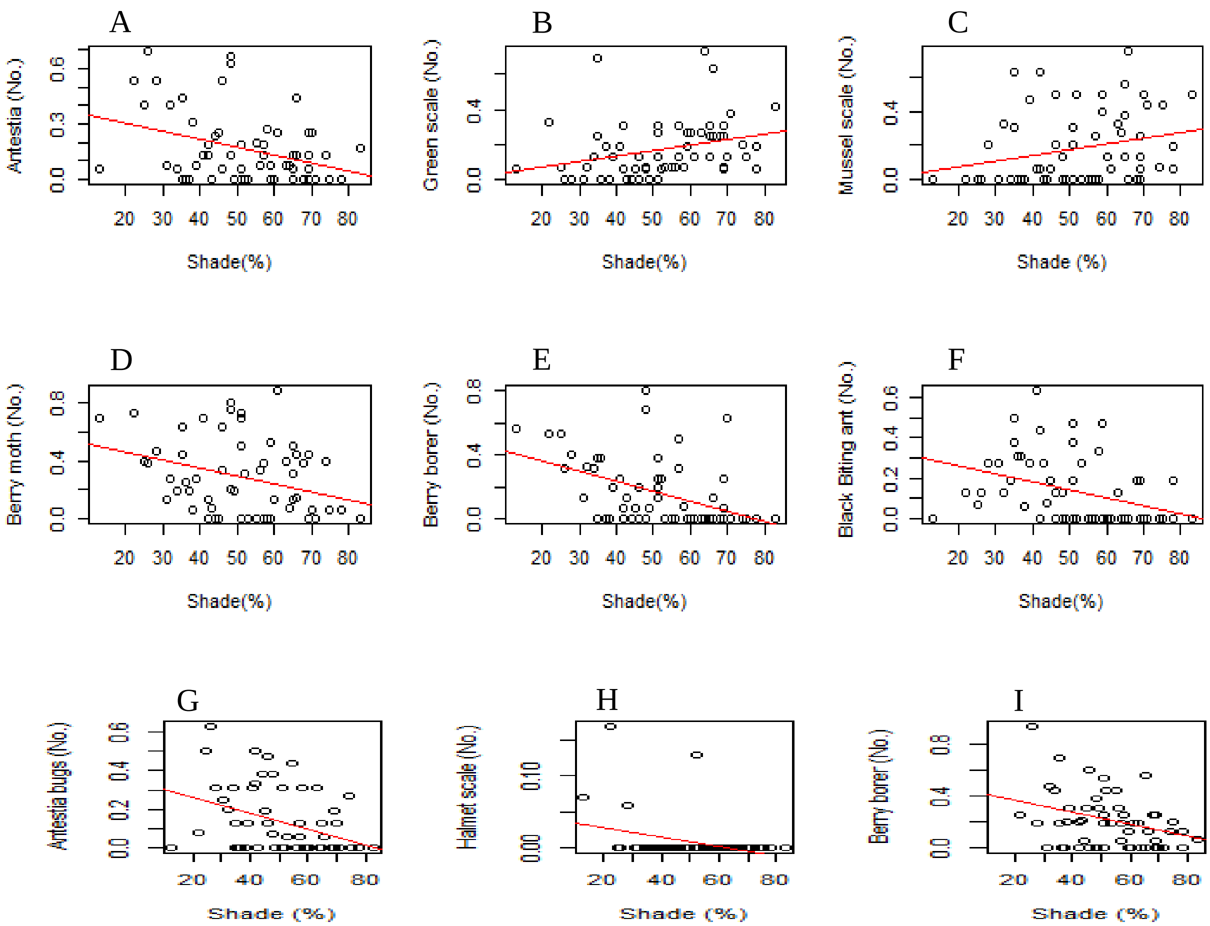

Figure 11. Effect of shade level on berry feeding and sucking insects during wet (A-F) and dry season (G-I) of 2018/2019 at Gomma-Gera, southwest Ethiopia

The association between berry feeding and scale insect pests such as Antestia bugs, berry moth, berry borer and black ant were negatively influenced, and green scale and mussel scale were positively associated with shade intensities during wet season (Appendix Table4). However, Antestia bugs, halmet scale and berry borer were negatively correlated with shade intensities during dry season (Appendix Table 5). Different insect type could have different response to same predictor variable in same coffee plot. Based on this result, the positive and negative effect of shade level depended on coffee insect species.

There are disagreement reports regarding influence of shade on coffee insect pests. Lopez-Bravo *et al.* (2012) and Jonsson *et al.* (2014; 2015) suggested that there are pests benefiting from high shade intensities. Most authors agreed that there are coffee insect pests that are negatively affected by high shade intensities (e.g. Pardee and Philpott, 2011; Mugo *et al.*, 2013); which may be species specific (Karungi *et al.*, 2015).

These different reports could be due to different gradients, and coffee insect species type. Staver *et al.* (2001) reported that the optimum shade level for pest suppression differ with climate, altitude, and soils, which need selection of tree species, arrangement and density. Cerda *et al.* (2017) also stated that the effectiveness of shade types for ecological services (for beneficial organisms and crop pests) depend on the interactions with different management gradients and altitude. Similarly, in Ethiopia, *Antestia intricata* is more serious pest in shaded coffee at low altitude (Million, 1987). Other study has shown that higher infestation of *Antestia thunbergii* in shaded compared to unshaded coffee by Mugo *et al.* (2013). Under high shade intensities the infestation of coffee insect pests was low and decreased as shade canopy closure increased. This could be due to the natural enemies, predators and disease causing pathogen that were abundantly found in unmanaged coffee production systems. De la Mora*et al. (*2008) reported that shaded coffee agroecosystems have few pest problems potentially due to higher abundance and diversity of predators of herbivores.

Shade trees affect the local abiotic environment by affecting temperature, humidity (Bote and Struik, 2001; Pezzopane *et al.*, 2011) and light intensity (Cavatte *et al.*, 2012). It would, therefore, be expected that as shade trees affect the temperature in coffee plots and indirectly coffee pest abundance could be affected (e.g. life span and special distribution).

4.3.3 Influence of altitude on berry feeding and sucking insects

In this study we examined the effect of altitude on coffee insect with range of 1506-2159 m.a.s.l. during wet and dry season of 2018/2019 at Gomma-Gera coffee plots. Antestia bugs, berry borer, slug, small snail, and medium snail were significantly influenced and decreased as altitude increased during wet season (Fig. 11). But, green scale, mussel scale and mealybugs significantly affected by altitude and increased with altitude (Fig. 11CDE) in the same season. During dry season Antestia bugs, mussel scale and coffee thrips were significantly influenced by altitude and decreased with altitude (Fig. 11FGH) and negatively correlated with altitude (Appendix Table 4 &5), which might be season dependent.

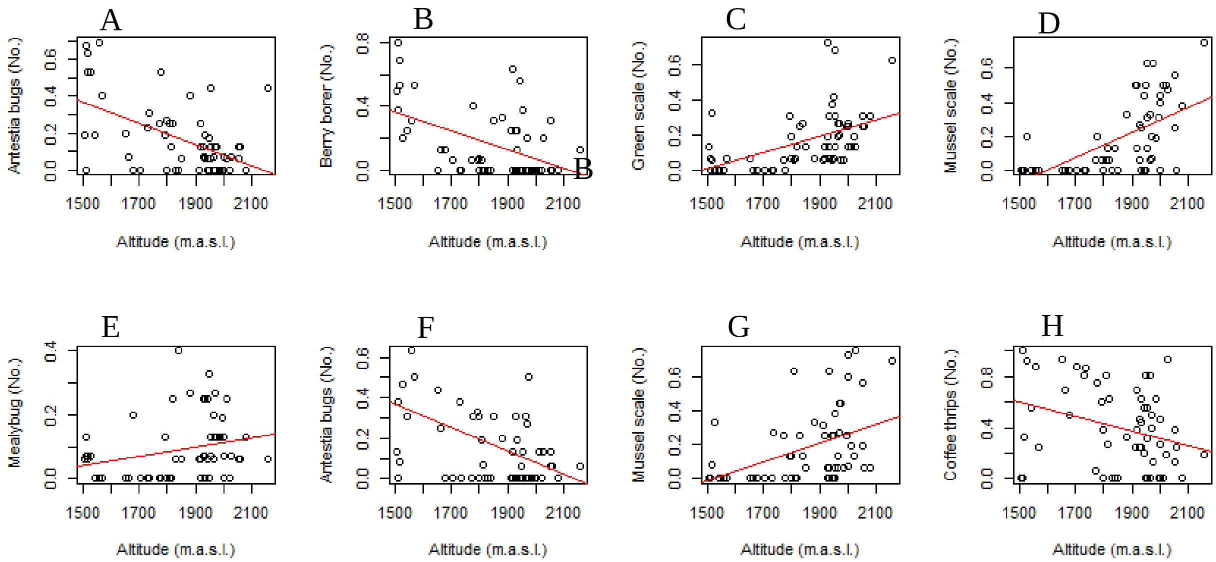

Figure 12. Effect of altitude on berry feeding and sucking insects during wet (A-E) and dry (F-H) season of 2018/2019 at Gomm-Gera, southwest Ethiopia

As altitudinal gradients increased the assessed pests were decreased, except green scale, mussel scale and mealy bugs. During dry season the percentage of coffee berry borer ranged from 0 to 94% (1506-1800m.a.s.l.) and 0-56% (1801 -2159m.a.s.l.) on leftover berries, and 13% coffee berry borer damage on leftover berries at an altitude of 2159m.a.s.l recorded in semi plantation coffee production system. However, Waller *et al.* (2007) reported that coffee berry borer has not been found at an altitude > 1370 m.a.s.l. This assessment indicated that coffee berry borer was not only found and considered to be lowland pest, but also occurred athigh altitude (2159m.a.s.l.). This might be due to the current weather variables that can create conducive environmental variables for coffee berry borer occurrence at high altitude (>2000m.a.s.l.) in Ethiopia. Jaramillo *et al*. (2009; 2011) stated that change in climate variables mainly an increase in average temperature in coffee growing regions has an impact on expansion of coffee berry borer to higher altitude where it infest *C. arabica.*

There are conflicting results on influence of altitude on coffee insect pests and could be species dependent. Some authors reported that, coffee grown in low altitude was severely affected than at higher altitude (Le Pelley, 1968). Similar reports are found on some coffee insect pests such as coffee berry borer; highest proportion of damaged berries, number of holes and number of adult coffee berry borer per berry on dried leftover berries at low-altitude (Eyasu *et al.*, 2019). Liebig (2017) also stated that coffee berry moth, leaf miner and green scale was high in low altitude than high and mid attitude. In contrast, there are coffee insect pests such as Antestia bugs Ahmed *et al.* (2016) on population density and Belay *et al.* (2018) on infestation and damage level of the Antestia bugs was higher in high altitude than lower altitude. On the one hand, these different findings could be explained by the range of included altitude.

4.3.4 Influence of coffee production system, shade level and altitude on slug and snails

Among gastropod (slug, medium, small and other snails) only slug was significantly influenced by coffee production system (Table 4). Snails (medium and small snail) was unaffected by coffee production system during both wet and dry seasons (Table 4).Medium snail was significantly (P=0.001) affected by shade during dry season. Similarly, altitude influences the abundance of slug and snails during wet and dry seasons and decreased as altitude increased (Table 4, Fig. 12A-E).

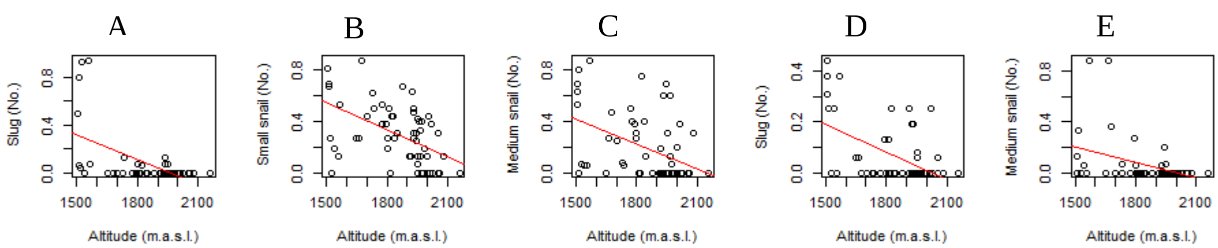

Figure 13. Effects of altitude on slug and snails during wet (A-C) and dry (D and E) season of 2018/20019 at Gomma-Gera, southwest Ethiopia

Until recently, slug and snails are not common in coffee and are not considered as a problem. Thus, in Ethiopia, there was no report on abundance and damage level of slug and snails (small, medium and other snails) under different coffee production systems, along altitudinal gradients and shade levels. In Ethiopia, slug and snails were highly observed on coffee trees during rainy season at Melko coffee field and Gomma farmers' field during field managements (weeding, pruning and de- suckering) and harvesting time (red berry picking) (Personal observation)).

From the assessment, the abundance of slug, small snail and medium snail were noticed in 35, 80 and 50% per 60 plots, respectively during wet season. Similarly, the abundance of slug, small snail and medium snails were recorded in 33.90, 42.37 and 18.64% per 59 plots, respectively during dry season. During wet (rainy) season the population density of slug ranged from nil to 22 per coffee shrub at an altitude of 1557m.a.s.l. in plantation coffee production system, on coffee leaves, berries and on coffee stem. All assessed gastropods (slug, small and medium snails) were abundantly found during wet season as compared to dry season. Reddy and Sreedharan (2006) reported high incidence of the giant African snails from the coffee areas of Araku valley zone in Visakha Agency of Andhra Pradesh during the rainy season of 2003. This was probably due to the moisture condition and rainfall that favored its growth and abundance. Kumar *et al.* (2018) stated that in hot and dry environmental conditions, they seek shaded and high humid places for shelter and when conditions are unfavorable, snails can become inactive and stops feeding.

Medium snail was negatively associated with shade intensities (Appendix Table 5) and decreased with shade intensities increased, that might be due to the abundance of the predators (e.g., birds) under densely shaded coffee field than least canopy cover. Perfecto *et al.* (2003) stated that a diversified and abundant canopy of shade trees enhances associated biodiversity of plants and animals, including insects and birds. For example in Mexico, De la Mora *et al.* (2008) reported shaded coffee agroecosystems have few pest problems potentially due to higher abundance and diversity of predators of herbivores.

5. SUMMARY AND CONCLUSION

The study was conducted to determine the influence of coffee production system, shade level and altitude on coffee insect pests, some gastropods and blotch miner parasitoids at Gomma-Gera, southwest Ethiopia in 2018/2019. The coffee insect pests, slug and snail abundance and damage varied under different management gradients. The higher leaf damaging insect damage was higher in plantation and lower in forest coffee production systems. The leaf damaging insect pests infestation and abundance was also higher at low altitude and under low shade canopy closure. From each of the four coffee production systems 100 leaves per plot mined by the coffee blotch miner was collected in plastic bags and stored in a plastic box under laboratory. The emerged parasitoids were classified in to different taxonomical groups under the microscope to family level. The highest (51.69%) and lowest (6.40%) parasitoids emerged from sample collected under semi forest and plantation coffee, respectively, while the highest (69.00 %) and lowest (12.74 %) coffee blotch miner adult moth fund in plantation and semi forest coffee production systems, respectively. Increased intensifications (forest coffee to plantation coffee) significantly increased the abundance of coffee insect pests, slug, and decreased coffee blotch miner parasitoids abundance. From previously recorded minor insect's coffee leaf skeletonizer, coffee berry moth and some gastropods were commonly detected on coffee. Most insect pests were negatively associated with altitude and shade, while few of them increased with both shade and altitude. Antestia bugs, berry moth and berry borer were reduced under shade intensities $\geq$ 30%, whereas, coffee blotch and serpentine miners decreased under shade level $\geq$ 50%. So, maintaining shade levels between 30-50% can be used as cultural insect pest's management options, but it depends on altitude, insect species, shade types (permanent and temporary shade) and season. Increase diversification (e.g. forest) increased the abundance of coffee blotch miner parasitoids and decrease coffee insect pests and some gastropods. In combination with other management options, parasitoids can help to reduce pest damage due to coffee blotch miner. It is essential to conserve indigenous natural enemies (parasitoids) of coffee insect pests that magnify the use of bio-agents, as component of integrated pest management. Identification and biology of coffee blotch miner parasitoids, slugs, snails, and impacts of slug and snails on coffee yield and quality is recommended for further study. The effects of shade types and species, coffee genotypes and other agronomic practices on insects are also recommended for further study.

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7. APPENDIX

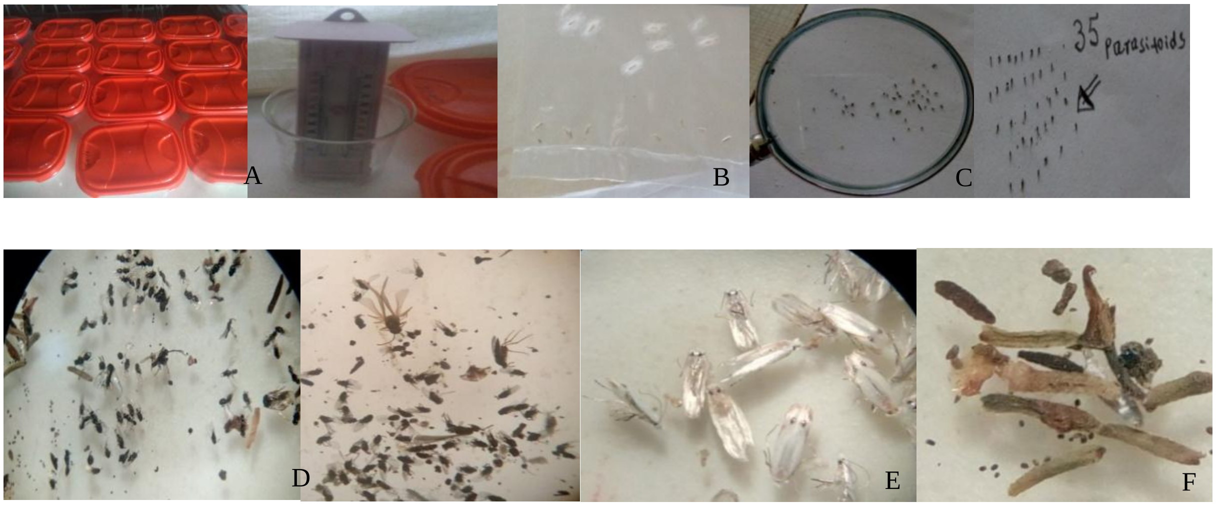
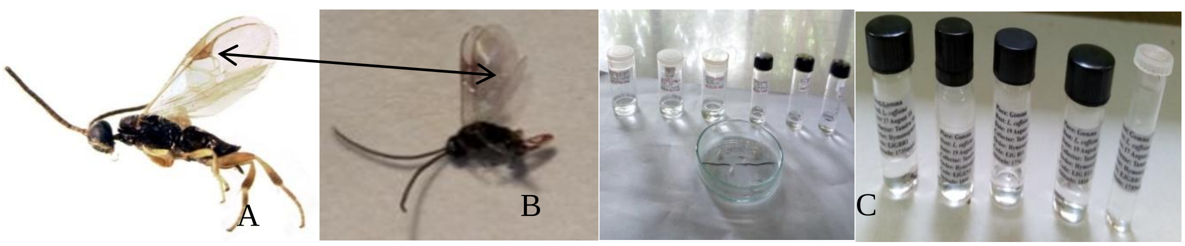


Figure 1. . Stored leaves collected in a plastic box (A) and plastic bag (B), and signs of emerged moths (B) and their parasitoids on white paper (C) emerged parasitoids under microscope (D) adult blotch miner moths and (E) parasitized larvae (F)



Appendix Figure 2. Morphological (wing structure) identification of emerged coffee blotch miner parasitoid. A. Apanteles bordagei (source: https://www.bing.com/images/wasb.Web.org), B. *Apanteles spp*. emerged from coffee blotch miner larvae and C. stored parasitoids in tubes

Appendix Table 1. Correlation matrices between common leaf damaging insect pests and shade and altitude during wet season of 2018/2019 at Gomma-Gera, Ethiopia

	Shade (%)	Altitude	Blotch miner	Serpentine miner	Leaf Skeletonizer	Blotch miner	Free feeding herbivore
Shade level (%)	1.00						
Altitude (masl)	0.45**	1.00					
Blotch miner *(L. caffeina)*	-0.34**	-0.75**	1.00				
Serpentine miner	-0.07	-0.33*	0.54**	1.00			
Leaf skeletonizer	0.16	-0.35*	0.55**	0.43**	1.00		
Blotch miner(*L. meyricki)*	0.18	0.09	-0.08	-0.09	-0.03	1.00	
Other free feeding herbivores	-0.16	-0.42**	0.68**	0.48**	0.40**	0.03	1.00

**= Significant and ** =highly significant difference between variables and L. show the genus name Leucoptera*

Appendix Table 2. Correlation matrices between leaf damaging insect pests and shade and altitude during dry season of 2018/2019 at Gomma-Gera, Ethiopia

	Shade (%)	Altitude	Blotch miner	Serpentine miner	Leaf Skeletonizer	Blotch miner	Free feeding herbivore
Shade level (%)	1.00	**0.46****	-0.19	**-0.28***	-0.16	NA	0.08
Altitude (m.a.s.l)		1.00	-0.13	-0.22	**-0.46****	NA	0.22
Blotch miner(*L. caffeina*)			1.00	0.44**	0.38**	NA	0.26*
Serpentine miner				1.00	0.53**	NA	0.28*
Leaf skeletonizer					1.00	NA	0.41**
Blotch miner (*L. meyricki)*						1.00	NA
Other free feeding herbivores							1.00

**=Significant and **=highly significant difference between variables, and NA=Not present during dry season*

Appendix Table 3. Correlation matrices between coffee blotch miner parasitoids and shade level and altitude during wet season of 2018 at Gomma-Gera, Ethiopia

	Shade level (%)	Altitude	Adult moth emerged	Parasitized larvae	Total Parasitoids emerged	Parasitism rate
Shade	1.00					
Altitude (m.a.s.l.)	-0.05	1.00				
Adult moth emerged	-0.04	**-0.71****	1.00			
Parasitized larvae	0.21	**0.64***	-0.34	1.00		
Total parasitoids emerged	0.09	0.55	**-0.58***	**0.83****	1.00	
Parasitism rate	-0.05	0.38	-0.62	0.45	**0.79****	1.00

**and **, shows significant and highly significant P-values at 5% probability level*

Appendix Table 4. Correlation matrices between berry feeding, sucking insects, slug, snails, and altitude and shade level during wet season of 2018/2019 at Gomma-Gera, Ethiopia

	Shade (%)	Altitude	Total Shrubs	Antestia bugs	Coffee aphids	B. thread scale	Helmet scale	Green scale	Mussel scale	Mealy bugs	Red spider mite	Whitefly	Stinging caterpillar
Shade level (%)	1.00												
Altitude(m.a.s.l.)	0.45	1.00											
Total Shrubs	-0.06	0.11	1.00										
Antestia bugs	**-0.37**	**-0.53**	-0.12	1.00									
Coffee aphids	-0.08	-0.09	0.06	0.33	1.00								
Black thread scale	0.03	0.10	0.08	-0.22	0.03	1.00							
Halmet scale	0.10	0.23	0.01	-0.19	-0.01	0.03	1.00						
Green scale	**0.30**	**0.49**	0.01	-0.09	0.00	0.04	0.02	1.00					
Mussel scale	**0.25**	**0.60**	0.03	-0.10	0.04	-0.05	0.11	0.50	1.00				
Mealy bugs	0.17	**0.26**	-0.15	-0.22	0.06	0.19	0.09	0.35	0.28	1.00			
Red spider mite	0.02	0.04	-0.31	0.08	-0.06	0.07	0.23	0.14	0.11	0.25	1.00		
Whitefly	-0.03	0.20	0.08	0.21	0.16	-0.11	0.07	0.18	0.31	0.06	-0.01	1.00	
Stinging caterpillar	0.17	0.17	0.11	-0.19	-0.04	0.06	-0.03	0.23	0.07	-0.01	-0.08	0.19	1.00
Stem borer	0.14	0.10	-0.34	0.02	0.04	-0.09	-0.10	0.28	0.17	0.44	0.18	0.19	0.20
Coffee berry moth	**-0.33**	-0.09	0.15	0.32	0.39	-0.03	0.24	0.10	0.00	0.25	-0.07	0.24	-0.03
Coffee berry borer	**-0.47**	**-0.49**	0.11	0.58	0.36	-0.28	-0.20	-0.12	-0.12	-0.09	0.01	0.10	-0.21
Creamatogaster ants	0.11	0.07	-0.11	-0.01	-0.01	0.19	0.18	0.28	0.14	0.43	0.15	0.24	0.16
Black biting ant	**-0.38**	-0.05	0.05	-0.02	0.15	0.17	-0.04	0.02	-0.13	0.13	0.00	0.07	-0.02
Driver ant	0.20	0.06	0.15	0.01	-0.01	0.25	-0.11	-0.08	0.09	0.23	-0.21	0.00	0.01
Slug	-0.19	**-0.56**	-0.03	0.58	0.18	-0.16	-0.05	-0.26	-0.23	-0.15	-0.08	-0.05	-0.13
Small snail	-0.16	**-0.51**	-0.16	0.19	0.24	0.07	-0.05	-0.33	-0.46	0.01	0.31	0.02	-0.08
Medium snail	-0.23	**-0.43**	0.05	0.10	0.21	0.12	0.08	-0.24	-0.35	-0.05	0.18	-0.02	0.09

(Table 4 continued)

	Stem borer	Berry moth	Berry borer	Creamatogaster ant	Black biting ant	Weaver ant	Slug	Small snail	Medium snail
Shade level (%)	0.14	**-0.33**	**-0.47**	0.11	**-0.38**	0.20	-0.19	-0.16	-0.23
Altitude(m.a.s.l.)	0.10	-0.09	**-0.49**	0.07	-0.05	0.06	**-0.56**	**-0.51**	**-0.43**
Total Shrubs	-0.34	0.15	0.11	-0.11	0.05	0.15	-0.03	-0.16	0.05
Antestia bugs	0.02	0.32	0.58	-0.01	-0.02	0.01	0.58	0.19	0.10
Coffee aphids	0.04	0.39	0.36	-0.01	0.15	-0.01	0.18	0.24	0.21
Black thread scale	-0.09	-0.03	-0.28	0.19	0.17	0.25	-0.16	0.07	0.12
Halmet scale	-0.10	0.24	-0.20	0.18	-0.04	-0.11	-0.05	-0.05	0.08
Green scale	0.28	0.10	-0.12	0.28	0.02	-0.08	-0.26	-0.33	-0.24
Mussel scale	0.17	0.00	-0.12	0.14	-0.13	0.09	-0.23	-0.46	-0.35
Mealy bugs	0.44	0.25	-0.09	0.43	0.13	0.23	-0.15	0.01	-0.05
Red spider mite	0.18	-0.07	0.01	0.15	0.00	-0.21	-0.08	0.31	0.18
Whitefly	0.19	0.24	0.10	0.24	0.07	0.00	-0.05	0.02	-0.02
Stinging caterpillar	0.20	-0.03	-0.21	0.16	-0.02	0.01	-0.13	-0.08	0.09
Stem borer	1.00	0.15	-0.01	0.39	0.21	0.13	0.01	0.06	-0.15
Coffee berry moth	0.15	1.00	0.45	0.26	0.31	0.15	0.24	0.07	0.25
Coffee berry borer	-0.01	0.45	1.00	-0.05	0.08	-0.16	0.34	0.32	0.40
Creamatogaster ants	0.39	0.26	-0.05	1.00	0.05	0.40	-0.01	0.25	-0.07
Black biting ant	0.21	0.31	0.08	0.05	1.00	-0.24	-0.07	0.08	0.01
Driver ant	0.13	0.15	-0.16	0.40	-0.24	1.00	0.03	-0.11	-0.09
Slug	0.01	0.24	0.34	-0.01	-0.07	0.03	1.00	0.08	0.14
Small snail	0.06	0.07	0.32	0.25	0.08	-0.11	0.08	1.00	0.48
Medium snail	-0.15	0.25	0.40	-0.07	0.01	-0.09	0.14	0.48	1.00

The bold numbers indicating the significant P value at 5% probability level. B. thread scale- black thread scale

Appendix Table 5. Correlation matrices between berry feeding, sucking insects, slug, snails,and shade and altitude during dry season of 2018/2019 at Gomma-Gera, Ethiopia

	Shade level (%)	Altitude	Total Shrubs	Antestia bugs	Coffee aphids	scale	Helmet scale	Green scale	Mussel scale	Mealy bugs	Red spider mite	Coffee thrips	whitefly
Shade level (%)	1.00	0.46	0.18	**-0.39**	-0.24	0.00	**-0.34**	-0.14	0.16	-0.03	0.21	-0.16	0.18
Altitude(m.a.s.l.)	0.46	1.00	0.15	**-0.46**	0.04	0.01	-0.17	0.12	**0.43**	-0.07	0.09	**-0.31**	0.13
Total Shrubs	0.18	0.15	1.00	0.15	0.22	0.11	-0.46	0.06	-0.04	0.10	-0.07	0.09	0.02
Antestia bugs	**-0.39**	**-0.46**	0.15	1.00	0.39	-0.12	-0.08	-0.11	-0.16	0.14	0.17	0.38	-0.12
Coffee aphids	-0.24	0.04	0.22	0.39	1.00	-0.07	0.13	-0.08	0.21	0.08	-0.11	0.14	0.02
Black thread scale	0.00	0.01	0.11	-0.12	-0.07	1.00	-0.06	0.70	-0.09	-0.05	-0.07	**-0.29**	-0.07
Halmet scale	**-0.34**	-0.17	-0.46	-0.08	0.13	-0.06	1.00	-0.03	-0.07	-0.05	-0.20	-0.04	-0.08
Green scale	-0.14	0.12	0.06	-0.11	-0.08	0.70	-0.03	1.00	0.04	-0.03	-0.11	-0.17	-0.04
Mussel scale	0.16	**0.43**	-0.04	-0.16	0.21	-0.09	-0.07	0.04	1.00	0.24	0.06	-0.02	0.48
Mealy bugs	-0.03	-0.07	0.10	0.14	0.08	-0.05	-0.05	-0.03	0.24	1.00	-0.15	0.23	0.19
Red spider mite	0.21	0.09	-0.07	0.17	-0.11	-0.07	-0.20	-0.11	0.06	-0.15	1.00	-0.01	-0.08
Coffee Thrips	-0.16	**-0.31**	0.09	0.38	0.14	-0.29	-0.04	-0.17	-0.02	0.23	-0.01	1.00	-0.13
Whitefly	0.18	0.13	0.02	-0.12	0.02	-0.07	-0.08	-0.04	0.48	0.19	-0.08	-0.13	1.00
Sting caterpillar	-0.06	-0.04	0.06	0.05	0.03	-0.03	-0.03	-0.02	0.27	0.87	-0.10	0.17	0.19
Berry borer	**-0.32**	-0.19	-0.12	0.38	0.01	0.31	0.10	0.33	0.04	0.10	0.24	0.19	-0.05
Fruit flies	-0.26	-0.23	0.23	0.23	0.14	-0.03	-0.12	0.02	-0.19	0.15	-0.09	0.17	0.11
Creamatogaster ant	-0.27	-0.21	0.01	0.37	0.09	-0.01	0.22	0.06	-0.28	-0.11	-0.05	-0.01	-0.23
Black biting ant	-0.10	**-0.28**	-0.01	0.13	-0.11	0.01	-0.11	-0.06	-0.12	-0.01	-0.14	0.02	-0.11
Driver ant	-0.22	-0.23	0.06	0.39	-0.07	-0.03	-0.03	-0.02	-0.11	-0.03	0.33	0.20	-0.04
Slug	-0.18	**-0.53**	-0.01	0.17	-0.13	0.13	0.08	-0.07	-0.16	0.05	0.06	-0.01	-0.07
Small Snail	-0.04	-0.06	-0.05	0.09	0.12	-0.12	0.03	-0.09	0.04	0.04	-0.01	0.00	-0.04
Medium snail	**-0.41**	**-0.39**	-0.19	0.24	-0.10	-0.02	0.15	-0.04	-0.24	-0.07	-0.06	0.03	-0.09

(Table 5 continued)

	Sting caterpillar	Berry borer	Fruit fly	Creamatogaster ant	Black ant	Driver ant	Weaver ant	Slug	Small Snail	Medium snail
Shade level (%)	-0.06	**-0.32**	-0.26	-0.27	-0.10	-0.22	0.02	-0.18	-0.04	**-0.41**
Altitude(m.a.s.l.)	-0.04	-0.19	-0.23	-0.21	**-0.28**	-0.23	0.01	**-0.53**	-0.06	**-0.39**
Total Shrubs	0.06	-0.12	0.23	0.01	-0.01	0.06	0.11	-0.01	-0.05	-0.19
Antestia bugs	0.05	0.38	0.23	0.37	0.13	0.39	0.15	0.17	0.09	0.24
Coffee aphids	0.03	0.01	0.14	0.09	-0.11	-0.07	-0.04	-0.13	0.12	-0.10
Black thread scale	-0.03	0.31	-0.03	-0.01	0.01	-0.03	-0.05	0.13	-0.12	-0.02
Halmet scale	-0.03	0.10	-0.12	0.22	-0.11	-0.03	-0.06	0.08	0.03	0.15
Green scale	-0.02	0.33	0.02	0.06	-0.06	-0.02	-0.03	-0.07	-0.09	-0.04
Mussel scale	0.27	0.04	-0.19	-0.28	-0.12	-0.11	-0.06	-0.16	0.04	-0.24
Mealy bugs	0.87	0.10	0.15	-0.11	-0.01	-0.03	-0.05	0.05	0.04	-0.07
Red spider mite	-0.10	0.24	-0.09	-0.05	-0.14	0.33	0.24	0.06	-0.01	-0.06
Coffee Thrips	0.17	0.19	0.17	-0.01	0.02	0.20	-0.01	-0.01	0.00	0.03
Whitefly	0.19	-0.05	0.11	-0.23	-0.11	-0.04	-0.03	-0.07	-0.04	-0.09
Sting caterpillar	1.00	0.06	0.15	-0.10	0.03	-0.02	-0.03	0.08	-0.09	-0.04
Berry borer	0.06	1.00	0.26	-0.06	-0.05	0.48	-0.15	-0.02	-0.10	-0.12
Fruit flies	0.15	0.26	1.00	0.19	-0.08	0.12	-0.04	0.15	0.15	0.14
Creamatogaster ants	-0.10	-0.06	0.19	1.00	-0.12	-0.06	0.28	0.20	0.15	0.31
Black biting ant	0.03	-0.05	-0.08	-0.12	1.00	-0.06	-0.10	0.07	-0.01	0.36
Driver ant	-0.02	0.48	0.12	-0.06	-0.06	1.00	-0.03	-0.07	-0.09	-0.04
Slug	0.08	-0.02	0.15	0.20	0.07	-0.07	0.07	1.00	0.03	0.31
Small Snail	-0.09	-0.10	0.15	0.15	-0.01	-0.09	-0.10	0.03	1.00	0.22
Medium snail	-0.04	-0.12	0.14	0.31	0.36	-0.04	-0.04	0.31	0.22	1.00

N/B: - The bold numbers indicating the significant P value at 5% probability level

Appendix Table 6. Coffee insect pests and Gastropods assessed from Gera–Gomma, Ethiopia in 2018/2019

Common name	**Scientific name**
Coffee blotch miner	*Leucoptera caffeina* (Washbourn)
Coffee blotch miner	*Leucoptera meyricki (*Ghesquiere)
Serpentine leaf miner	*Cryphiomystis aletreuta* (Meyrick)
Coffee leaf skeletonizer	*Leucoplema dohertyi* (Warren)
Other free feeding herbivores	--
Antestia bugs	*Antestiopsis* spp
Coffee Berry borer	*Hypothenemus hampei (*Ferriere)
Coffee Berry moth	*Prophantis smaragdina* (Butler)
Coffee thrips	*Diarthrothrips Coffeae* (Williams)
Coffee fruit flies (Tephritidae)	*Trirhithrum coffeae* (Bezzi)/*Ceratitis fasciventris* (Bezzi) or *C.anonae* (Graham)
Coffee Aphids (black)	*Toxoptera aurantii* (Boyer de Fanscol.)
Black thread scale	*Ischnaspis longirostris* (Signoret)
Coffee Green scale	*Coccus alpinus* (De Lotto)
Mussel scale	*Lepidosaphes beckii* (Newman)
Stinging caterpillar	*Parasa vivida* (Walker)
Red coffee mite	*Oligonychus coffeae* (Nietner)
Halmet scale*	*Saisettia coffeae* (Walker)
Mealy bugs (Long tailed mealy bugs)*	*Planococcus kenyae*
Whitefly*	Aleyrodoidea (Hemipteran)
Coffee stem borer*	
Craematogaster ant*	
Black Biting ant*	
Slug	
Small snail	
Medium snail	
Other snails	

***=*Indicates the coffee pests need identification*