Coffee Berry Insect Pests and their Parasitoids in the Afromontane Rainforests of Southwestern Ethiopia

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Abstract: A study was conducted to investigate the presence, intensity and damages caused to coffee berries by major insect pests of coffee in wild coffee populations in Afromontane rainforests of Southwestern Ethiopia. The parasitoids associated with those insect pests were also studied. Based on ecological descriptions of forest coffee population, each forest locality was stratified in to three forest sites. In each stratum, 40 coffee trees were randomly taken for insect pests and parasitoids collection; whereas 16 random coffee trees were used to study the incidence of the pests on coffee berries at different phenological stages. Fifteen insect pest species in 10 families under five orders were recorded. Among the insects recorded, *Ceratitis fasciventris* (Bezzi) and *Ceratitis anonae* Graham were new records for Ethiopia. Similarly, *Prorops nasuta* and *Psyttalia* spp. were new parasitoids reported for the first time in Ethiopia. The damage caused by coffee berry moth was low and analysis of variance revealed that there is a significant difference ($P < 0.05$) among the forest coffee populations. Fruit fly mean incidences on ripen coffee berries reached 52.12% ± 14.31, 71.08% ± 4.48 and 82.73% ± 3.61 at Yayu, Berhane-Kontir and Bonga, respectively. Mean damage by *Hypothenemus hampei* was less than 10% in most of the forest coffee populations, which is relatively low incidences in less disturbed ecosystem. In general, difference in occurrences of insect pest incidences between and within forest coffee populations **was** observed, which could be due to variations in ecology, and diversity of the insect pests and their parasitoids. From the results, it is thought that these forest coffee sites would be used as the main genetic resources for exploration of insect pests and their natural enemies in the future, which undoubtedly needs detailed research work.

Keywords: *Coffea arabica*; Afromontane Rainforest; Insect Pests; Parasitoids; Incidence

1. Introduction

Coffee berries (beans) are the final product for consumption. Several insect pests are known to attack berries at different phenological development stages and affect both quality and quantity of the product. Coffee berry infestation by insects starts at bud formation and flowering stage. General feeders such as larvae of lepidoptera damage buds, whereas scale insects and aphids infest and suck the sap from the plant at all times during their nymphal and adult stages. The most injurious pests at green berry stages are Pentatomid and Mirid bugs (Le Pelley, 1968; Million, 1987; Crowe, 2004). Small green berries are attacked by general feeders including Coleoptera, many Lepidoptera, scale insects and thrips. The pentatomids *Antestiopsis* spp. feed on small green berries and mostly cause berry drop-off. Fully developed green berry is the stage at which the beans differentiate developing a hard endosperm and are suitable for many general feeders like berry-boring Lepidoptera (Le Pelley, 1968; Million, 1987; Crowe, 2004). Ripe berry is the stage at which pulp becomes soft, sweet and the parchment surrounding the endocarp hardens. The seeds or beans at this stage are not easily attacked by almost all sucking insects. Several authors reported ripe berries are attacked by fruit fly larvae (Le Pelley, 1968; Mekuria *et al.*, 1995; Million, 2000; Crowe, 2004; Esayas, 2005). Following the ripening process of coffee, the fruit either falls to the ground or remains on the tree, if not harvested. The pulp starts drying up and the stage is referred to as over ripened or mummified berries and liable to be attacked by *Hypothenemus hampei* (Million, 2001; Esayas *et al.*, 2003).

There are different coffee growing and production systems in Ethiopia mainly due to varying level of forest trees associated with coffee, the nature of coffee tree regeneration and resource level of growers. In general, based on the level of human intervention (management practices), the coffee system in Ethiopia is categorized in to four as forest, semi-forest, Garden and plantation coffee systems (Demil, 1999; Paulose and Demil, 2000; Workafes and Kassu, 2000; Taye and Tesfaye, 2001). The forest coffee type is genetically heterogeneous and serves as a source of gene pool to improve coffee varieties for disease and insect pest resistance/tolerance, productivity and quality through breeding. In general, crop production systems can affect insect pests population build up directly or indirectly. In Ethiopia, over forty-seven species of insect pests were recorded in plantation and garden coffee production systems (Million and Bayisa, 1986; Million, 1987, 2000).

Coffee is produced in more than 80 countries worldwide and it is by far Ethiopia's most important export crop in the national economy as it accounts for 41% (FAO, 2006) and 35% (Tadesse *et al.*, 2008) of the total agricultural export earnings; and 10-20% of the total government revenue (FAO, 2006). Insect pests are among the number of factors considered to limit coffee production and productivity. Among the coffee berry damaging insects, Antestia bug cause 9% yield loss and 48% coffee bean darkening (Million, 1988) and coffee berry borer cause up to 60% damage on dry left-over berry (Million, 2001; Esayas *et al.,* 2003), in all-case damage assessment focussed on plantation coffee production system. On the other hand, there is a

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ISSN 1992-0407

complete lack of data on insect pests of coffee in the afromontane rainforest of southwestern Ethiopia from where *C. arabica* **was** originated and distributed to the world. Insect pest status information is a vital and prominent issue for further research work in such area.

The diversity and the economic value of the Ethiopian coffee gene pool and its forest habitat as well as the institutional framework of forest users have been studied (CoCE I, 2007; Chemeda *et al.,* 2008). The *in-situ* conservation of wild coffee is an extremely useful approach in biodiversity conservation as the conservation of coffee genetic diversity is connected with the conservation of forest species diversity (CoCE I, 2007). However, the status of coffee berry damaging insects and their parasitoids has not been surveyed, nor described and no scientific information thereof is available in such a genetically diversified ecosystem. So, a detailed study was essential in order to supplement *in-situ* conservation of the genetically diversified forest coffee pool and associated flora and fauna for sustainable use. Therefore, this study was initiated to investigate and document coffee berry insect pests and their parasitoids; and estimate the associated incidence in relation to coffee berry developmental phenology in the afromontane rainforests of southwestern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Areas

The study was conducted in the afromontane rainforests of Yayu (Geba-Dogi), Berhane-Kontir and Bonga Forest Coffee Populations (FCPs) in the 2007/2008. The Yayu FCP (PI) is found in the western part of the Oromia Regional State along the Geba and Dogi Rivers, whereas the Berhane-Kontir (PII) and Bonga (PIII) FCPs are situated in the Southern Nations Nationalities and People's Regional State, SNNPS (Figure 1). These forest sites have served as a focal point for biodiversity conservation in general and strategic diagnostic research as FCPs in particular. In general, they are benchmark areas for the Ethiopian Government as the National Forest Priority Areas (NFPAs) and are declared forest coffee conservation areas too. Altitudes, geographical co-ordinates (latitudes and longitudes), slopes and aspects of the study areas and sites are shown in Table 1.

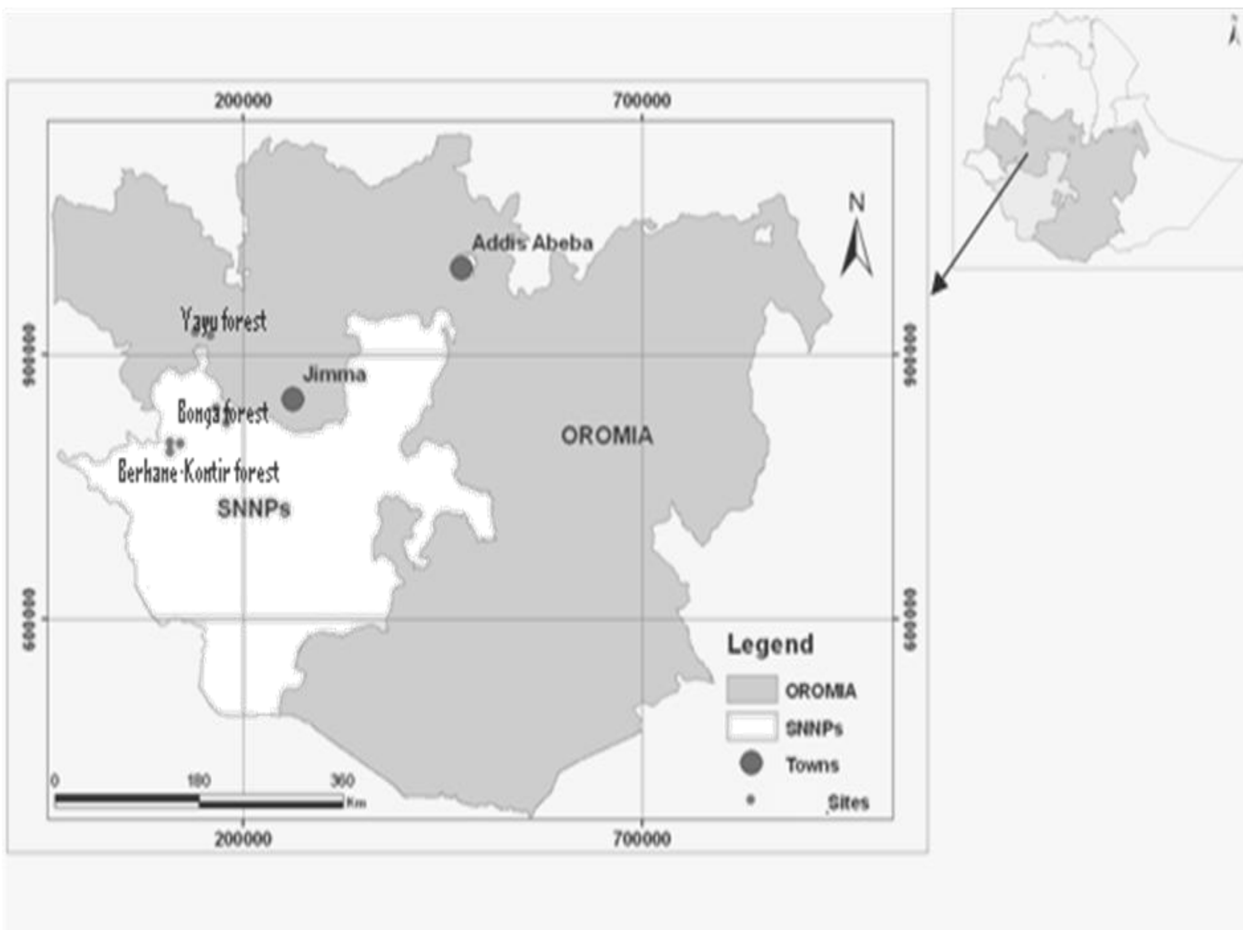


Figure 1. Map of Ethiopia showing regions with forest areas of montane rainforests of southwestern Ethiopia.

Table 1. Description of the study sites in the afromontane rainforests of southwestern Ethiopia.

Forest population	Forest site*	Elevation (masl)	Coordinates		Slope (%)	Slope aspect
			Latitude (N)	Longitude (E)		
Yayu (PI)	Yayu-1 (SI)	1493	08⁰ 24' 11"	35⁰ 47' 44"	10	East
	Yayu-2 (SII)	1491	08⁰ 23' 98"	35⁰ 47' 40"	16	West
	Yayu-3 (SIII)	1496	08⁰ 23' 10"	35⁰ 47' 62"	20	West
Berhane-Kontir (PII)	BeKo-1 (SI)	1051	07⁰ 07'43"	35⁰ 26' 16"	15	North
	BeKo-2 (SII)	1084	07⁰ 07' 16"	35⁰ 26' 29"	13	Northeast
	BeKo-3 (SIII)	1134	07⁰ 06' 52"	35⁰ 26' 33"	20	East
Bonga (PIII)	Alemgano-1 (SI)	I744	07⁰ 20' 01"	35⁰ 13' 39"	5	East
	Alemgano-2 (SII)	1739	07⁰ 20' 31"	35⁰ 13' 32"	10	East
	Yabito (SIII)	1894	07⁰ 19' 04"	'35⁰ 03' 31"	8	Northwwest
	JARC	1753	07⁰ 47' 03"	036⁰ 00' 00"	-	-

**JARC = Jimma Agricultural Research Center wherein laboratory based experiment was conducted, masl = Meters above sea level*

2.2. Assessment of Insect and their Parasitoids

A study on coffee berry insect pests and their natural enemies was conducted in the Afromontane rainforests of southwestern Ethiopia. For every FCP, 3 representative sites labelled as SI, SII and SIII; each with 100 m x 100 m area were selected for the study. This classification was made based on general uniformity of coffee trees (5-7 years old), shade status and elevation of the FCP sites.

The study/sampling plots environmental features were described using GPS for coordinates and elevation; and clinometers and compass were used to find the slope gradients and aspects, respectively. To obtain representative insect samples during different coffee fruit phenological stages, the study was made 4 times in all selected forest populations. From each site, 40 coffee trees were randomly taken and every encountered insect feeding on the coffee plant was collected using different methods including hand collection, aspirator and sweep net. Sampling was made at different times of the day at 6 am, 10 am, 12 am, 4 pm and 6 pm to widen the chance of catching all coffee berry damaging insects. All insect samples collected were labelled and the co-ordinates, altitudes, slopes, date of collection and developmental stage of the pest were registered. Specimens were brought to the Entomology Laboratory of the Jimma Agricultural Research Center (JARC) either for preservation or for further rearing to adults or parasitoid emergence using parts of the host plant as a source of food to determine their identity on the basis of adult characteristics. Daily emerged natural enemies were collected, coded and preserved separately for identification purpose. Finally, all insect specimens and parasitoids were identified at the Biosystematics Department of the International Center for Insect Physiology and Ecology (ICIPE), Nairobi, Kenya.

2.3. Experimental Tree Selection and Damage Assessment

From the three sites of each FCP, 16 coffee trees were randomly picked and tagged for berry damage assessment. Further, each coffee tree was stratified into three-canopy layer and a pair of branches from each layer was selected for data collection at different coffee berry phenological development stages as described by Alemseged *et al.* (1997).

Coffee berry moth incidence and berry damage assessment at green berry stage was made by counting total and damaged berries from lower, middle and upper canopies of selected branches. Whereas, assessment for fruit fly incidence on ripened coffee berries was conducted using destructive sampling method from each sampling tree and canopy branch. Three hundred ripened berries were sampled every time and sampling was made twice a week for two consecutive months during the harvesting period. The collected berries were dissected the same day by removing the skin with a scalpel. The number of fruit fly larvae in the mucilage and between the beans was scored against each berry to determine the percentage of the fruit fly infestation along with the number of larvae per infested berry in each FCP and site.

To determine the level of damage caused by *H. Hampei,* 200 left-over dried coffee berries were collected from 30 random coffee trees for each site following the methods of Remond and Cilas (1997) and Baker (2000). Beisdes, fallen berries were unruffled from the ground around all sampled trees of the montane rainforests' coffee areas, kept in labelled paper bags, and then brought to the Entomology Laboratory of the JARC. Finally, the entire berries were dissected with a surgical blade to confirm the damage by *H. hampei* under the microscope. The percentage of damaged berries was computed by dividing the cumulative damaged berries to the total berries collected.

2.4. Data Analysis

The percentage of damaged berry data was computed using the SAS package –V8 for windows from the SAS Institute Inc. Cary NC/USA. Nested design of Proc Mixed was used to analyze variation in infestation across the FCPs. Whenever significant differences were detected for means at 5% probability level, means were separated using the Tukey's Honestly Significant Difference Test. The SPSS statistical software program, version 13, was employed to all descriptive statistics. Correlation between level of damage on dried left-over and fallen coffee berries, and regression for relationships between altitudinal changes and percentages of infestation of dried coffee berries (fallen and left-over) in various FCPs were tested using the MINTAB software.

3. Results

3.1. Coffee Berry Insect Pests and their Parasitoids

The study revealed that on *Coffea arabica* in montane rainforests of southwestern Ethiopia, 15 insect species in 10 families under five orders were recorded and identified (Table 2). Of the identified insects, *Ceratitis fasciventris* (Bezzi) and *C. Anonae* (Graham) were new records for Ethiopia. Not all collected insects occurred commonly within every forest coffee ecosystem. Based on the number of recorded site and rate of recurrence, insect in forest ecosystems of southwestern Ethiopia were classified into two groups: sporadic and frequently occurring insect pests of coffee. Sporadic character were recorded once or twice within one or two FCPs, while the frequently observed insect pests caused detectable damage symptoms and were recorded for more than two times in every FCP. Of the insect pests of coffee berries, *C. fasciventris, C. anonae, Trirhithrum coffeae, H. hampei* and *Prophantis smaragdina* were among the frequently recorded coffee berry insect pests in all of the FCPs. Natural enemies, predominantly parasitoids of commonly occurring insect pests of coffee including Antestia bug, coffee berry borer and fruit flies have been collected and identified to the family level and in some cases to species level (Table 3).

3.2. Extent of Coffee Berry Damage

3.2.1. Damage by Coffee Berry Moth, *Prophantis Smaragdina*

Prophantis smaragdina was the most frequently observed insect and prevalent at endosperm enlargement stage. Studies at this stage indicated that the percentage of incidences ranged between 0.65% at Yayu to 11.62% at Berhane-Kontir FCPs. The analysis of variance showed that there was a significant ($P < 0.05$) difference among the FCPs (3.00±1.165%c at Yayu, 7.49±1.575%a at Berhane-Kontir and 5.21±1.268%b at Bonga areas).

Table 2. Insect pests associated with forest coffee berries in south western Ethiopia.

Order	Family	Common name	Scientific name	Occurrence	FCP**
Hemiptera	Pentatomidae	Antestia bug	*Antestiopsis intricata* (Ghesquiere & Carayon)	Sporadic	1 and 2
Homoptera	Diaspididae	Black thread scale	*Ischnaspis longirostris* (Signoret)	Sporadic	2 and 3
Lepidoptera	Lycaenidae	Berry butterfly	*Duodryx lorisona coffeae*	Sporadic	2 and 3
Homoptera	Aphididae	coffee aphid	*Toxoptera aurantii* (Boyer de Fanscocombe)	Sporadic	2 and 3
Coleoptera	Scolytidae	Coffee berry borer	*Hypothemus hampei* (Ferriere)	Frequent	1, 2 and 3
Lepidoptera	Pyralidae	Coffee berry moth	*Prophantis smaragdina* (Butler)	Frequent	1, 2 and 3
Hemiptera	Miridae	Coffee capsid	*Lamprocapsidea coffeae* (China)	Sporadic	1 and 2
Homoptera	Stictococcidae	Coffee cushion scale	*Stictococcus formicarius* Newstead	Sporadic	2 and 3
Diptera	Tephritidae	Coffee fruit flies	*Trirhithrum coffeae* Bezzi	Frequent	1, 2 and 3
Diptera	Tephritidae	-	*Ceratitis fasciventris (*Bezzi)*	Frequent	1, 2 and 3
Diptera	Tephritidae	-	*Ceratitis anonae* (Graham)*	Frequent	1, 2 and 3
Homoptera	Coccidae	Green scale	*Coccus alpinus* De Lotto	Sporadic	2 and 3
Homoptera	Coccidae	Helmet scale	*Saissetia coffeae* (Walker)	Sporadic	2 and3
Homoptera	Diaspididae	Hussel scale	*Lepidosaphes bekii* (Newman)	Sporadic	2 and 3
Homoptera	Diaspididae	Rufous scale	*Selenaspidus articuslatus* (Morgen)	Sporadic	2 and 3

** = Insect pests of coffee reported for the first time from Ethiopia; ** = FCP = Forest Coffee Populations where 1 =: Yayu, 2 = Berhane-Kontir and 3 = Bonga*

Table 3. Parasitoids of coffee berry insect pests collected from afromontane rainforests of south western Ethiopia.

Host (Common name)	Stage of host attacked	Parasitoids		Species	FCP**
		Order	Family		
Antestia bug	Egg	Hymenoptera	Scelionidae	CNI	1 and 2
			Eupelmidae	CNI	
Coffee berry borer	Larval	Hymenoptera	Bethylidae	*Prorops nasuta* *	1 and 2
Fruit flies	Larval	Hymenoptera	Braconidae	*Psyttalia* spp. (Opiine subfamily)	1, 2 and 3

** = Coffee insect pest parasitoid for the first time reported from Ethiopia, CNI = Could not be identified, ** = FCP = Forest Coffee Populations where 1 =: Yayu, 2 = Berhane-Kontir and 3 = Bonga*

3.2.2. Damage by Fruit Flies, *Ceratitis* spp. and *Trirhithrum coffeae*

The damage caused by fruit flies (*C. anonae*, *C. fasciventris* and *T. Coffeae)* on Arabica coffee berries population at all the locations and sites varied significantly (Table 4). The level of damaged berries (incidence percentage) ranged from 31.3-69.0, 61.7-79.7 and 78.0-88.0% at Yayu, Berhane-Kontir and Bonga, respectively. The means of damaged berries (incidence percentage) recorded at the respective aforementioned locations were 52.12, 71.08 and 82.73%. Similarly, the number of fruit fly larvae per infested ripen coffee berries varied between and within the FCPs. The means of number of larvae per infested berry were 1.26, 1.44 and 1.76 at Yayu, Berhane-Kontir and Bonga, respectively (Table 5).

Table 4. Percent of ripen coffee berries infested with fruit fly larvae in afromontane rainforest Arabica coffee populations of southwestern Ethiopia.

Forest population	Forest site	Damaged berries (%) (range and mean)*
Yayu (PI)	SI	50.70-69.00 (61.57±12.94)bc
	SII	42.30-60.00 (51.15±12.52)ab
	SIII	31.30-56.00 (43.65±17.47)a
	Mean	52.12
Berhane-Kontir (PII)	SI	69.30-72.30 (70.77±2.12)c
	SII	71.00-79.70 (76.13±6.15)cd
	SIII	61.70-69.00 (66.33±5.16)c
	Mean	71.08
Bonga (PIII)	SI	83.00-87.00 (85.10±2.83)d
	SII	78.00-81.00 (79.77±2.12)cd
	SIII	79.70-88.00 (83.33±5.87)d
	Mean	82.73

**Means within a column followed by same letter(s) are not significantly different according to Tukey's test at P > 0.05. Figures in parenthesis are mean ± standard error of mean (SE).*

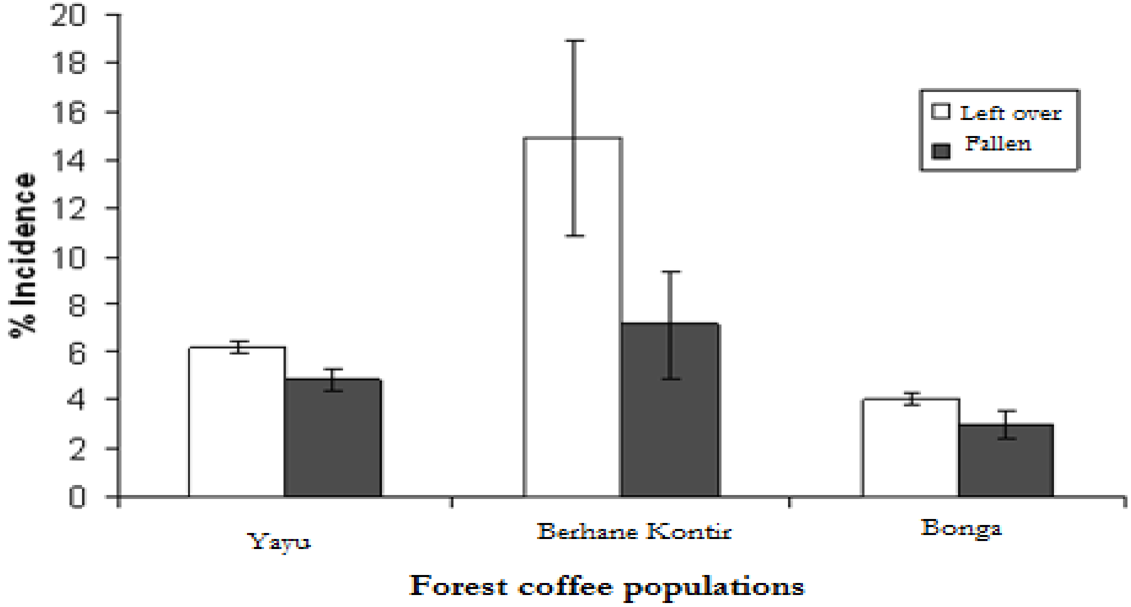
Table 5. Average fruit fly larvae density per infested coffee berry in montane rainforest of south western Ethiopia.

Forest population	Forest site	Mean ± SE (Standard error of mean)
Yayu (PI)	SI	1.34±0.08
	SII	1.39±0.11
	SIII	1.05±0.09
	Mean	1.26±0.09
Berhane-Kontir (PII)	SI	1.35±0.07
	SII	1.66±0.08
	SIII	1.30±0.07
	Mean	1.44±0.07
Bonga (PIII)	SI	1.90±0.08
	SII	1.83±0.08
	SIII	1.54±0.06
	Mean	1.76±0.07

3.2.3. Damage by Coffee Berry Borer, *Hypothenemus hampei*

Mean percent incidence of *H. hampei* on left-over dried berries ranged between 9.50-22.27, 6.00-6.90 and 3.63-4.50% at Berhane-Kontir, Yayu and Bonga with mean incidence of 14.91±4.02, 6.49±0.25 and 4.04±0.25%, respectively. Besides, fallen berries showed comparatively low incidence which ranged from 4.00-5.50% (Yayu), 4.49-11.67% (Berhane-Kontir) and 2.00-3.92% (Bonga) FCPs, with an average incidence of 4.83±0.44, 7.15±2.26 and 2.96±0.55% in that order (Figure 2). The mean percent incidence of *H. hampei* across the study areas was 4.98% for fallen berries and 8.48% for left-over dried coffee berries. Across FCPs, 88.89% of fallen berries and 77.78% of left-over dried coffee berries showed an incidence of less than 10%. In general, significantly high incidence was revealed at the Berhane-Kontir FCP followed by Yayu and Bonga for both left-over dried and fallen coffee berries, though wider range of infestations were recorded among sites of the same FCP.

The result of a simple correlation study between intensity of damage on left-over dried coffee berries and fallen berries collected from the same FCP showed a high and positively significant correlation ($r = 0.96$). A significant ($P < 0.05$) negative regression was detected between mean percentage incidences of left-over dried coffee berries and the variation in altitude across the study areas ($r = -0.79$) (Figure 3). Analogous results were also observed for the fallen coffee berries ($r = -0.63$, $P < 0.05$).



Error bars = Standard Error of Means
Figure 2. Incidence (Mean ± SE) of coffee berry borer at three Afromontane rainforests in southwestern Ethiopia

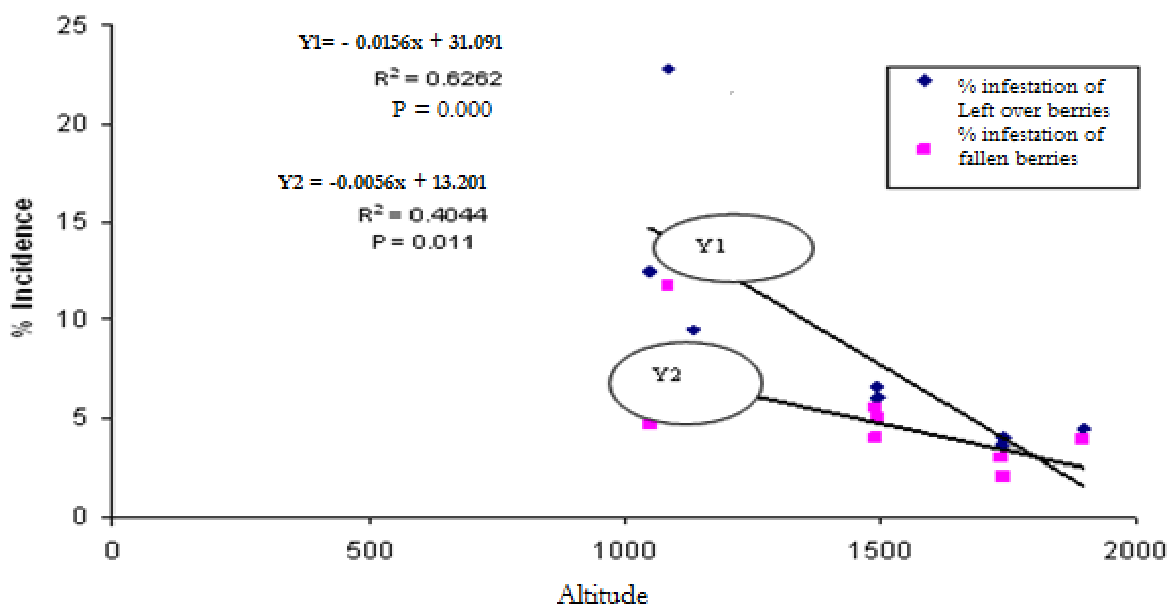


Figure 3. Regression for relationships between altitudinal range and percent incidence of coffee berry borer in the montane rainforests of southwestern Ethiopia

4. Discussion

Fifteen insect pest species in 10 families under five orders were recorded from the montane rainforests of southwestern Ethiopia. Among these, two species of insect pests and two parasitoids were reported for the first time in Ethiopia. Tadesse (2003) and Fayera (2006) opined that there is no research information regarding insect pests on coffee in the montane rainforest ecosystem. However, this study revealed that there exists more than a dozen of insect pests attacking coffee trees in the FCP of montane rainforest areas. Thus, the present study on the occurrence, incidence and distribution of coffee insect pests and their parasitoids in the montane rainforests of southwestern Ethiopia is the first of its kind in the country. The insect pest populations were high, however, their incidence was relatively low compared to other production systems, probably due to the efficient role of natural enemies (Million and Bayissa, 1986; Million, 1987) in such undisturbed ecosystem.

Species of fruit fly parasitoids including the brown and black *Psyttalia* spp. and unidentified species under the opiine sub-family were reared from the samples in the assessed areas. In Ethiopia, Million and Bayisa (1986) reported that *C. rosa* paratisized by *Opius* sp. nr. *africanus* and *Opius* sp. nr. *desideratus* were collected from different coffee plantations. Correspondingly, Clausen (1978) mentioned as largest diversity of parasitoids attacking fruit infesting tephritid flies found in the opiine braconid sub-family. Opiines have long been known as a biological control agent against tephritid pests (Clausen *et al.,* 1965; Wharton, 1989). Species of the genus *Psyttalia* are among the most common parasitoids reared on fruit infesting flies in Africa (Clausen *et al.,* 1965; Clausen, 1978; Wharton, 1989). Wharton (1997a, b) and Billah (2004) stated of the existence of 11 *Psyttalia* species in Africa, with a few potentially undescribed species being reared from various fruits sampled in Kenya. The two most important species in terms of historical use as biological control agents are *P. concolar* (Szepligenti) and *P. humilis* (Silvestri) described from Tunisia and South Africa, respectively, in Clausen *et al. (*1965).

Prorops nasuta was found in Berhane-Kontir and Yayu FCPs attacking *H. hampei* at larval stage. The parasitoid was recorded for the first time in Ethiopia. However, Million (2001) reported that there were parasitoids attacking *H. hampei* in different parts of the country and forwarded as research gap for parasitoid collection and identification. *P. nasuta* is indigenous to Africa, but the parasitoid was introduced to Latin American countries, where *H. hampei* is the most economically important pest of coffee. Murphy and Rangi (1991) mentioned that *P. nasuta* was considered as a classical biological control agent in Brazil by introducing it from Uganda in 1929 and in 1962 from Peru. Since that time, the wasp became established in the field and artificially dispersed. In Kenya, *H. hampei* was parasitized by *P. nasuta* and *Heterospilus coffeicola* Schmied and *P. nasuta* alone caused 18% parasitism Mugo *et al.* (1997).

Prophantis smaragdina was relatively the most frequently observed insect pest at the expanding coffee berry phenology with the mean incidence of 5.07% across FCPs. Million and Bayisa (1986) reported that *P. smaragdina* was the commonly found insect pest attacking green coffee beans. Similarly, Crowe (2004) reported that this pest was a minor pest of Arabica coffee for many years in East and South Africa including Ethiopia. However, recently the damage due to this pest has become serious especially on intensively managed coffee plantations.

The mean incidence of fruit fly attack was 52.12% at Yayu, 71.08% at Berhane-Kontir and 82.73% at Bonga FCPs. Coffee fruit fly larvae infestation in ripen coffee berries was prevalent in all assessed FCPs. The mean incidence ranged between 31.3 and 88.0% across forest coffee ecosystems. In line with this, research conducted around Tepi revealed that infestation ranged from 55.2 to 58.1% (Esayas, 2005). Abasa (1973) stated that there was a seasonal emergence of fruit flies in a coffee plantation at Ruiru/Kenya, and up to 85% infestation occurred during the peak season at ripening stages. Three fruit fly species were recorded from studied FCPs, where *C. fasciventiris* was the most dominant one followed by *T. coffeae* and *C. anonae*. Similarly, research results showed that *C. arabica* is a host plant to fruit fly species like *C. fasciventiris, C. anonae* and *C. rosa* (Copeland *et al.,* 2006). On the other hand, Esayas (2005) reported three species of Tephritids fruit flies Viz. *C. rosa, T. coffeae* and *C. capitata* infesting Arabica coffee. The most probable reason for the difference between the present finding and the previous findings could be; attributed to the fact that before revision of the sub-genus *Ceratitis (Pterandrus)* Bezzi (Diptera: Tephritidae), *C. fasciventris* was categorized under *C. rosa* as a sub-species. Therefore *C. fasciventris* was reported as *C. rosa* (de Meyer and Freidberg, 2006). Mekuria *et al.,* (1995) also reported that more than three species of fruit flies infested coffee berries in Ethiopia, *C. rosa* and *T. coffeae* were the dominant species. In surveys conducted in Kenya by Gabson (1970) and Mukiama and Muraya (1994) results showed that *C. capitata, C. rosa* and *T. coffeae* infested coffee in that country.

The mean incidence of *H. hampei* was low as it accounted for only 8.38 and 4.98% incidence on dried left-over and fallen berries, respectively. In Kenya, infestation level of up to 80% during the peak season was reported with similar magnitude of crop losses with a reduction in quality of the remaining yield (Masaba *et al.,* 1985). Up to 80% of berries were also attacked in Uganda, Ivory Coast and Brazil, 90% in Malaysia, 96% in Congo and Tanzania (Waterhouse and Norris, 1989). In New Caledonia up to 87% berry infestation in full sun light coffee plantations was reported (Giordanengo, 1992). Surveys in southwestern Ethiopia indicated that the highest mean percentage infestation (60%) was recorded at Tepi (Esayas *et al.,* 2004). The author also found that in the Yeki and Godere Districts on large coffee plantations and at research centers like Melko (JARC), Mettu and Tepi the level of infestation was considerably high. Similarly, Million (2001) reported maximum berry infestations from Tepi research sub-center with up to 73% damage. The most probable reason for the low infestation in FCPs could be due to relatively low ecological disturbance, in which the *H. hampei* and its natural enemies live in a relatively balanced way, where natural enemies can perform well. Monocultures are notoriously vulnerable to pest out-breaks (Gibson and Jones, 1977) and the results of some studies suggested that structural and floristic complexity reduce the probability of severe pest out-breaks in plant communities (Andow, 1991; Altieri and Nicholls, 1999; Grimble and Laidlaw, 2002; van Mele and van Lenteren, 2002).

Regression analysis showed that the incidence of *H. hampei* and altitude had significant negative relationship. This finding is in agreement with Soto-Pinto *et al.* (2002). They stated that a step-wise regression analysis showed a significant and negative estimate parameter for the relationship between berry borer and altitude ($r = -0.63$; $P < 0.05$), suggesting that at higher elevation, berry borer could be less problematic. Similarly, Esayas *et al.* (2004) reported that altitude among other factors limited the distribution of the borer as indicated by a significant and negative correlation between altitude and infestation level (r = -0.60; P < 0.05). Hence, coffee berry borer infestation in the coffee growing areas is more severe in lower the altitude than in the higher altitudes.

5. Conclusion

In conclusion, most of the insect pests collected and identified were minor pests in the forest coffee ecosystems. In other coffee production systems or other countries, however, they may cause very serious damage when conditions allow. In the FCPs of southwestern Ethiopia, insect pest infestation was found to be less important due to the fact that they had been well controlled by their natural enemies. Incidence varied from one forest coffee area to another and within the FCPs depending on environmental condition, genetic diversity of Arabica forest coffee and the abundance of natural enemies. The over all result of this study indicated that no coffee tree was free from insect pest attack and at least one insect pest species was associated with the host. The damage, however, was mostly negligible and very low. The present research result suggest that additional control measure for berry damaging insects in the rainforest coffee may not urgently be recommended, but the finding complements other research findings that recommended to conserve remnant forests and its biodiversity in the southwestern part of the country.

Insects in general and Lepidoptera in particular are indicators of ecological diversity, so more detailed studies of insect abundance in each FCP should be conducted including the contribution of insects in coffee pollination. Furthermore, detailed studies of the genetic variability of *H. hampei* and its natural enemies should be undertaken to know factors responsible for the low population of the world wide important insect pest of coffee.

6. Acknowledgements

The authors gratefully thank the Center for Development Research (ZEF) of Bonn University, Germany for financial support to carry out the project and all persons, who directly or indirectly contributed to the fulfilment of this study. The authors would also like to extend heartfelt thanks to the Jimma Agricultural Research Center (JARC), Ethiopia and the International Center for Insect Physiology and Ecology (ICIPE), Nairobi/Kenya for technical and material supports during sample preparation and identification.

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