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Impact of Coffee berry borer on Global Coffee Industry: Review

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Abstract: **Coffee berry borer (CBB) is the most serious and widespread insect pest of coffee. It affects the productivity of this crop in many countries. It is a major pest of Robusta coffee and low altitude Arabica coffee which the immature and mature berries leading to a crop loss, both in yield and quality. *Hypothenemus hampei* is a pest of immature and mature coffee berries, causing no damage to the leaves, branches or stem. Adult female *H. hampei* bore galleries into the endosperm of the coffee seed, causing different economic losses by premature fall of young berries, by increased vulnerability of infested ripe berries to fungus or bacterial infection, and by reduction in both yield and quality of coffee, reducing the income of coffee growers. The coffee berry borer can cause yield losses of 30-35% with 100% of berries infested at harvest time and damage may be greater if harvest is delayed. The lesions caused by the activity of the scolytid create an entry site for secondary infection by bacteria and fungi. Two species of bacteria, *Erwiniastewartii* (Smith) and *E. salicis* (Day) Chester (*Enterobacteriaceae*), have been implicated as the agents responsible for wet rot in the mesocarp of immature berries superficially damaged by *H. hampei* (which had then rejected and left the berries). The economic damage associated with *H. hampei* is premature fall of berries, beans of low commercial value, downgraded quality and flavour of the coffee. Its infestation rate varies with altitude for instance; Coffee grown in low altitudes is severely affected than at higher elevation.**

Keywords: **Coffee berries, Hypothenemus hampei, Robusta coffee, Vulnerability, Yield losses.**

1. INTRODUCTION

Coffee is the most important agricultural commodity in the globe with annual revenues exceeding US $ 70 billion (Vega, 2008). Small stakeholders with less than 5 ha of farming land supply 70% of the total global output which is about 9 million metric tons annually. The genus Coffea comprises of 103 species (Davis *et al*., 2006) although only two are economically important, namely Coffea arabica (arabica) and Coffea canephora (robusta) Pierre ex A. Froehner. Coffee is grown in 80 countries in > 10 million hectares of land (FA0, 2013) and an estimated 125 million coffee farmers rely on the crop for subsistence (Lewin *et al*., 2004). Coffea arabica constitute 70% of the coffee that is traded globally. It is considered to be of higher quality and fetches a higher market value than the better yielding C. canephora due to a better aroma and less caffeine levels (Medina *et al*., 2006). Moreover, coffee is the most valuable tropical export crop worldwide; however, it has been affected by increasing temperatures and associated damages due to a variety of pests and diseases (Jaramillo *et al*., 2011). In particular, the coffee berry borer (CBB), which is the most damaging coffee pest in all coffee-producing countries, has recently been found in higher elevations as a result of rising temperatures across the tropics (Mangina *et al*., 2010). CBB damage is likely to worsen over time because of a projected increase in both the number of insect generations per year and the number of eggs laid per female borer (Jaramillo *et al*., 2010).

The Coffee berry borer (CBB) or Broca, *Hypothenemus hampei* (Ferrari) is the most serious and widespread insect pest of coffee. It affects the productivity of this crop in many countries (Baker, 2002). Endemic to Central Africa or originally native to Africa, the pest has spread to almost every coffee-producing country in the world with the Eastern Africa region being not exceptional. It is a major pest of Robusta coffee and low altitude Arabica coffee (Le Pelley, 1968). The CBB is a small beetle measuring 2mm in length. It attacks the immature and mature berries. The female beetles (CBB) lay 30-50 eggs inside a coffee cherry, which hatch and develop inside. Both the adult female and larvae damage the coffee berries of all developmental stages causing defects or the cherry drops off the tree leading to a crop loss, both in yield and quality (Le Pelley, 1968; Baker, 2002). The economic impact due the CBB infestation is substantial, in terms of loss as yield and quality. Annual global losses due to the pest are estimated at US $ 500 million (Vega *et al*., 2009), and due to diminished yields and quality (Damon, 2000). In Africa, yield losses as high as 96% have resulted from Coffee berry borer attack on coffee (Waterhouse and Norris, 1989). This damage may increase poverty and food insecurity among approximately 120 million people in South America, East Africa, and Southeast Asia (Vega *et al*., 2003; Jaramillo *et al*., 2011). Smallscale, asset-poor coffee producers can be disproportionately affected because of their limited financial ability to invest in costly adaptation strategies as well as in more intensive pest and disease management strategies. The objective of this paper is to review the impacts of coffee berry borer on global coffee industry.

2. GLOBAL HISTORY AND DISTRIBUTION OF COFFEE BERRY BORER (*HYPOTHENEMUS HAMPEI*)

The coffee berry borer, *Hypothenemus hampei* Ferrari (Coleoptera: Scolytidae) is the most serious pest of commercial coffee in virtually all producer countries of the world (Le Pelley, 1968; Baker, 1984; Waterhouse and Norris, 1989; Murphy and Moore, 1990; Barrera, 1994). *Hypothenemus hampei* was first recorded in coffee seeds of unknown origin being traded in France in 1867 (Waterhouse and Norris, 1989) and first reports of the pest in Africa were from Gabon in 1901 (Le Pelley, 1968) and Zaire in 1903 (Murphy and Moore, 1990). However, the true origin of this pest remains unclear. The production of coffee began with Arabica coffee, *Coffea arabica* L. (Rubiaceae) and spread very rapidly to many parts of the world during the 16th and 17th centuries, with a complex interchange of genetic material, originating from Ethiopia, then undergoing propagation in Saudi Arabia, Amsterdam and Paris, from where it was distributed widely throughout the suitable growing areas of the world, particularly within European colonies (Purseglove, 1968). It is probable that some of this material was contaminated with *H. hampei*. The situation regarding the domestication of robusta coffee, *Coffea canephora* Pierre ex Fröhner (Rubiaceae), from West and Central Africa, and the part that it played as a host and in the dissemination of the pest is even less clear, due to the confused taxonomy of this species, which was cultivated in Africa before the arrival of the Europeans (Purseglove, 1968).

Evidence is that *H. hampei* is not found above 1500 m, which is the preferred altitude of arabica coffee, which originates from Ethiopia. Robusta coffee, from West and Central Africa, being found at lower altitudes, is therefore more likely to be the original host of the pest (Baker, 1984). However, differing opinions concerning the geographical origin of the pest have been presented, such as Corbett (1933) who suggested that *H. hampei* originated in Angola, in southwest Africa and Murphy and Moore (1990) who proposed two scenarios; that either *H. hampei* itself originated from North East Africa, the original home of arabica coffee, or, that arabica coffee was contaminated in Ethiopia or Saudi Arabia (where it was first imported for cultivation at some unknown date before the 15th century) by the passage of infested berries of West African robusta coffee through the area.

The suggestion that the original host of *H. hampei* was *C. canephora* was initially strengthened by the report from Davidson (1967), who concluded that the pest was absent from Ethiopia, the home of arabica coffee. Apart from a few reports of characteristically damaged berries from the southwest of the country, there was no further mention of *H. hampei* in Ethiopia until Abebe (1998) reported the pest to be present at all but one of the sites studied. The borer was found at all altitudes from below 1000 m to over 1900 m, in the major coffee-growing areas in the south and south-west of the country, with relatively higher infestation at lower altitudes. This situation could indicate a recent introduction of the pest, or, a very effective control of the borer by natural enemies or plant resistance, which would then suggest that *H. hampei* has co-existed with arabica coffee for a very long time in Ethiopia, possibly originating there.

3. BIOLOGY AND LIFE CYCLE OF COFFEE BERRY BORER (*HYPOTHENEMUS HAMPEI*)

The family Scolytidae can be divided into two main subdivisions; the sub-cortical feeders or bark beetles and the woodborers or ambrosia beetles, which include the genus *Hypothenemus*. Ambrosia beetles live in symbiotic association with fungi that feed on wood and are then in turn fed upon by the beetle which may never directly feed upon the wood itself (Sponagel, 1994). The coffee berry borer is a small beetle measuring 2 mm in length (Baker, 1984). Briefly,

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according to Barrera (1994), the synovogenic female lays between 31 and 119 eggs within a single coffee berry of suitable ripeness and the life stages consist of the egg, larva, pupa (with a brief pre-pupal stage) and adult. The juvenile stages last for an average of four (egg), 15 (larva) and seven (pupa) days, respectively, at 27˚C. The complete life cycle may take from 28 to 34 days. Reports of the life expectancy of the adults are varied; males may live for 20 - 87 days and females for an average of 157 days (Barrera, 1994). Where coffee is present all year round, as occurs in Uganda, *H. hampei* may exceed eight generations a year. *Hypothenemus hampei* feeds on and reproduces in the endosperm of the seed of the coffee berry, burrowing through exocarp, mesocarp and endocarp to reach it, which may take, under optimum conditions, up to 8 hours (Sponagel, 1994)

In the inter-harvest or dry season, female *H. hampei* remain semi-inactive in old berries waiting for the first rains, which stimulate females to emerge and search for new berries in which to begin the next cycle (Barrera, 1994). The rain itself is not the trigger; the coffee berries simply become waterlogged and uninhabitable. An extended dry season can reduce *H. hampei* infestations due to the sensitivity of the scolytid to humidity levels up to 150 adults may be found in a single berry during the inter-harvest period, as reproduction continues until the resources are totally exhausted (Baker, 1984). Waterhouse and Norris (1989) stated that a female *H. hampei* could live for 81 days without food. The pest becomes inactive below 15˚C, very close to the lower end of the temperature range of the coffee plant at 16˚C (Sponagel, 1994). Female *H. hampei* mate a few hours after emergence with sibling males, which have reduced degenerate wings and do not leave the berry. Twelve days after hatching, the phototropism of the female inverts and the female emerges from the berry during the hours of maximum sunlight. Dissemination of the pest is generally considered to take place by long and short distance flight, passive transport (animals, vehicles, humans, wind, etc.) and the coffee trade (Sponagel, 1994).

4. KEY ECOLOGICAL FACTORS

Mendez and Velasco (1987) and Sponagel (1994) concluded that early flowering, stimulated by early rainfall, offered an extended period of available ripe coffee berries for *H. hampei* and was therefore the single most important environmental factor responsible for the economic damage caused by this pest. Robusta coffee, *C. canephora*, suffers more damage due to its continuous production of flowers and, therefore, the constant availability of berries in various stages of development throughout the year. The berries take longer to mature than those of *C. arabica*, tend to be infested at an earlier stage of development and are easier to penetrate, having a thinner and softer exo- and endocarp. The higher temperatures and humidity of the lower altitudes where robusta coffee is grown also favour the pest (Klein-Koch *et al.*, 1988). Arabica coffee, grown at lower elevations, is very attractive to *H. hampei*, possibly due to a weakening of the plant, which grows best at altitudes above 1220 m (Friederichs, 1924). The extended flowering period resulting from the cultivation of a mixture of robusta and Arabica coffee is also conducive to the pest (Ortiz-Perschino, 1991).

Humidity is frequently mentioned as a key factor determining infestation levels and it is a generally held view that *H. hampei* survives for longer and reproduces better in humid, shady conditions. However, Decazy (1992), Baker *et al*. (1989) and Sponagel (1994) found no relationship between shade and infestation levels. In Honduras, Muñoz *et al*. (1987) found higher *H. hampei* infestation levels in medium shade than in full sun or heavy shade and that the pest attacked both shaded and full-sun plantations equally. The pest and its brood are protected from humidity fluctuations inside the maturing berry, but ambient humidity can become critical during the interharvest period when coffee berries become black and dry. Conversely, excessive humidity during the post-harvest period may cause accelerated rotting of coffee berries on the ground, reducing the food supply (Ticheler, 1961).

CBB distribution and crop damage are related to several environmental factors. For example, there were positive relationships between CBB infestation and altitude (Damon, 2000; Constantino *et al*., 2011; Jaramillo *et al*., 2011), positive relationships between the number of CBB individuals and temperature (Teodoro *et al*., 2009; Jaramillo *et al*. 2011), and higher infestation levels in dry years compared with wetter years (Constantino 2010, Constantino *et al*., 2011, Rodríguez *et al*., 2013, Mariño *et al*., 2016). Previous studies also reported a relationship between CBB infestation and altitude (Damon 2000, Soto-Pinto et al. 2002, Constantino 2010; Jaramillo et al. 2011). In Ethiopia and Colombia, CBB infestation was higher at altitudes below 1,000–1,200 masl and lower above 1,600–1,900 masl (Abebe 1998, Constantino 2010). In Mexico, the CBB was sampled in an altitudinal range similar to that of Puerto Rico (100–1,250 masl), and CBB infestation was higher from 500 to 1,000 masl (Baker et al. 1989). Much less has been reported on the relationship between CBB population per fruit and altitude. We observed a tendency similar to infestation, with almost double the number of individuals in fruits collected at altitudes over 200 masl.

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5. IMPACTS OF COFFEE BERRY BORER ON GLOBAL COFFEE INDUSTRY

Hypothenemus hampei is a pest of immature and mature coffee berries, causing no damage to the leaves, branches or stem. *Hypothenemus hampei* (Ferrari) is the only species that directly attacks the seed (Vega *et al*., 2003). Adult female *H. hampei* bore galleries into the endosperm of the coffee seed, causing three types of economic losses: 1) premature fall of young berries, 2) increased vulnerability of infested ripe berries to fungus or bacterial infection, and 3) reduction in both yield and quality of coffee, reducing the income of coffee growers (Damon, 2000; Jaramillo *et al*., 2006). The coffee berry borer can cause yield losses of 30-35% with 100% of berries infested at harvest time (Barrera, 2008). Damage may be greater if harvest is delayed. The lesions caused by the activity of the scolytid create an entry site for secondary infection by bacteria and fungi. Two species of bacteria, *Erwiniastewartii* (Smith) and *E. salicis* (Day) Chester (*Enterobacteriaceae*), have been implicated as the agents responsible for wet rot in the mesocarp of immature berries superficially damaged by *H. hampei* (which had then rejected and left the berries) (Sponagel, 1994).

Coffee Berry Borer larval and adult stages are responsible for coffee damage through feeding. The pest infestation reduce yield and quality of the berries and in some instances, coffee berries abscise prematurely (Le Pelley, 1968; Murphy and Moore, 1990). Holes created by the borers during penetration also serve as entry points for bacterial and fungal pathogens (Damon, 2001). According to Baker *et al*. (2002), the conversion factor (i.e., the amount of parchment coffee obtained from a given amount of freshly picked coffee berries after processing) under low H. hampei pressure is 5:1. However, high infestation can alter this ratio by up to 17:1, leading to serious economic repercussions for farmers (Baker et al., 2002; Jaramillo et al., 2011). In addition, high H. hampei pressure may cause coffee to be prohibited from export due to international marketing policies that restrict export of coffee berries with more than 1.5% damage caused by insect pests (Duque and Baker, 2003).

Worldwide losses incurred due to H. hampei damage is estimated at >US $ 500 million annually and affects more than 20 million households in developing countries (Vega *et al*., 2009; Vega *et al*., 2015). Crop losses due to the pest of up to 96% have been reported in some East African countries (Magina, 2005). In Kenya for instance, infestation levels of up to 80% have been reported (Masaba *et al*., 1985) and the pest is reported to contribute to an on-going decline in coffee production in the country. In Ethiopia also, Loss due to coffee berry borer inflict up to 60% damage on dry left over coffee berries (Million, 2000). Climate change particularly the raise in temperature in coffee growing areas has aggravated the problem by creating an environment conducive to the rapid growth of the pest Abdu (Abdu and Tewodros, 2013).

The economic damage associated with *H. hampei* is premature fall of berries, beans of low commercial value, downgraded quality and flavour of the coffee. Its (CBB) infestation rate varies with altitude. Coffee grown in low altitudes is severely affected than at higher elevation (Murphy and Moore, 1990). The CBB attacks the immature and mature berries where both the adult and larval stages cause crop loss ranging from 50-100% with reduction in quality of the remaining yield (Le Pelley, 1968; Waterhouse and Norris, 1989). Mugo (2008) survey on CBB spread in Kenya indicated that the pest is still a problem with all the coffee growing areas surveyed indicating the presence of CBB. Infestation levels ranging between 0.6- 25 % was recorded. However, the percentage CBB infestation decreased with increase in management levels. The percentage of CBB mortality experienced from natural enemies attack increased with increase in coffee management levels. Many coffee growers, especially in poor tropical regions, do not have the resources to manage the coffee berry borer and consequently may lose up to 80% of their berries. In some cases, even if most berries are still un-infested, the whole crop may not be sellable because current regulations prohibit the export and import of coffee batches with any signs of infestation. Thus, your morning latte is now a bit more expensive, but this way you are supporting the farmers who do manage the beetle on their farms.

6. MANAGEMENT METHODS

6.1. Cultural Control

Cultural control strategies are usually developed to suit specific pests. The Coffee berry borer easily survives from one cropping season to the next while inside the coffee berries that have either dropped on the ground or dried on the trees. The most effective cultural approach in control of this pest is to pick up and completely destroy the berries that are the potential reservoirs for CBB, at the end of the cropping season through deep burying or burning. However, this control method is regarded as tedious and rather very labour intensive especially picking berries off the ground (Le Pelley, 1968; Baker, 1999). Therefore it's advocated that during coffee picking, berry dropping to the ground should be kept to a minimum. Proper drying of coffee beans also helps in reducing the CBB infestation.

6.2. Chemical Controls

Chemical control has limited effectiveness because of the biology and feeding behavior of this pest. Nearly the entire life cycle of CBB takes place inside the coffee cherry. For that reason, insecticides applied to control the CBB can be rarely effective against it. For any insecticides to be effective either wholly or partially, it must be applied before the CBB adults get into the hardened coffee bean (Mugo, 2010). This to be achieved, the insecticide requires to be sprayed four to five months after the crop has flowered since this is the period when the coffee beans hardened and suitable for CBB attack (Mugo, 2010). Several insecticides have been evaluated and recommended for management of major insect pests of coffee (Le Pelley, 1968), with some reported to reduce populations of biological control agents. Endosulfan, an organo-chlorine, is mostly used in coffee to manage Coffee berry borer in many parts of the world. Its frequent use has led to the development of some resistance against it as reported in New Calendonia (Pacific Ocean) ((Brun *et al*., 1989).

The CBB has an interesting life history that facilitates faster development of resistance enables it to readily develop pesticide resistance. Most CBB are females in a ratio of 13:1(Brun *et al.*, 1995). Since the males are flightless, they mate with their sisters because they never leave the cherry in which they are born. This results in genetic inbreeding. When the mutation for endosulfan resistance occurs, this rapidly spread through a population because of this inbreeding (Brun *et al.*, 1995). This development of resistance to endosulfan if it becomes widespread may prove devastating to the management of CBB. Organic pesticides extracted from plants/ botanicals such as Neem and pyrethrums, are usually used in organic farming. Extracts from Neem and Tephrosia are used in Tanzania to control the CBB with encouraging results (Magina, 2005). Trapping of CBB for instance by use of "Brocap" usually reduces the CBB infestation .

6.3. Biological Control

Biological control through use of natural enemies (parasitoids, fungal pathogens and parasitic nematodes) enhanced with effective cultural controls and selective insecticide application helps to keep this pest in check. These includes parasitoids such as *Prorops nasuta* Watson, *Heterospilus coffeicola* Schmied, *Cephalonomia stephanoderis* Betrem, *Phymastichus coffea;* fungal pathogens, the *Beauveria bassiana* and parasitic nematodes.

A number of these biocontrol agents are indigenous to Eastern Africa region with reported parasitism levels ranging from 18 to 59% (Le Pelley, 1968). In Kenya for instance, three parasitic wasps; *Prorops nasuta*, Phymastichus *coffea* and *Heterospilus coffeicola (*Murphy *et al.*, 1986; Infante *et a*l,. 1995) have been recorded. These parasitoids have been exported to countries like Colombia, Guatemala, Honduras, Jamaica, El Salvador, Ecuador, India, Brazil and Mexico for the control of CBB (Murphy *and* Rangi, 1991*;* Baker *et a*l., 2002*).* Other natural enemies such as *Beuveria bassiana* have also been exported to other countries as part of classical biocontrol where promising results in parasitism levels have been achieved (Baker *et a*l., 2002). The *P. coffea* unlike the other parasitoids obtained from East Africa, it parasitizes the adults female CBB before it enter the coffee bean and moves from berry to berry (Baker *et a*l., 2002). Thus *P. coffea* is considered to be a potentially useful biological control tool in management of CBB

7. CONCLUSION AND RECOMMENDATIONS

The Coffee Berry Borer is a serious insect pest of coffee crops worldwide. Historically, the strategies to overcome this pest have not been aligned with environmentally friendly schemes and problems such us resistant to chemical insecticides arrived soon as expected. The pest control measures rely heavily on use of synthetic pesticides. Costs of inputs particularly pesticides, have become unaffordable by most farmers in Africa, and the increasing concern about pesticides residue risks have evidently led to the need of developing alternative pest management strategies. To effectively manage Coffee berry borer, combination of various pest management strategies, which are economically viable, sustainable and environmentally friendly in the coffee growing areas should be advocated. Therefore, in view of the above, the inclusions of biocontrol, botanicals, cultural and selective insecticides are suitable strategies for managing the coffee berry borer.

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- Pruning should be done after harvest and before pruning remove all the remaining berries, including immature out-of-season berries, raisins (cherries dried on the tree) and drops (fallen berries).
- Set baited traps in the pruned fields where the coffee berry borers are emerging from the berries
- Reduce heavy shade by Pruning coffee to keep the bush as open as possible to create a less humid environment for the beetle
- Picking should take place at least once a week in the main harvest season and once a month at other times to prevent over-ripe infested cherries falling to the ground where adult females can survive and attack out-of-season cherries.
- Cherries should be left on the ground as little as possible. Dropped cherries will provide a source for beetles to reinfest the next crop.
- All infested cherries should be destroyed by burning, deep burying or if possible rapid sun drying.
- Before a main flowering the crop should be stripped completely.

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