Bulletin of Entomological Research (2000) **90**, 453–465

REVIEW ARTICLE

A review of the biology and control of the coffee berry borer, *Hypothenemus hampei* (Coleoptera: Scolytidae)

A. Damon*

El Colegio de la Frontera Sur, Apdo. Postal 36, Tapachula, Chiapas, México

Abstract

The coffee berry borer, *Hypothenemus hampei* Ferrari, is a serious problem for the majority of the world's coffee growers and has proved to be one of the most intractable of present day pests. Despite a great deal of research, control still depends largely on the application of the organochlorine insecticide endosulfan, which is damaging to the environment, or a series of cultural and biological control methods which give variable and unpredictable results. This review summarizes the most important aspects of the biology and ecology of *H. hampei* and its control and identifies weak points in the knowledge about this pest. Emphasis is placed upon an analysis of the non-chemical control methods available and suggestions are offered for novel ecological and environmental factors worthy of further research, in the search for viable and sustainable control methods.

Introduction

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 & Norris, 1989; Murphy & Moore, 1990; Barrera, 1994). Costa Rica, Cuba and Panama currently remain free of the pest and for them quarantine is of vital importance (Baker, 1999a).

Hypothenemus hampei was first recorded in coffee seeds of unknown origin being traded in France in 1867 (Waterhouse & Norris, 1989) and first reports of the pest in Africa were from Gabon in 1901 (Le Pelley, 1968) and Zaire in 1903 (Murphy & 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 & 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

---

*Fax: 0052 962 81015
Email: adamon@tap-ecosur.edu.mx

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 south-west 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.

Damage caused by *H. hampei*

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 three types of economic losses: (i) boring and feeding activities of adults and progeny cause a reduction in yield and quality of the final product (Moore & Prior, 1988); (ii) due to physical damage, attacked mature berries become vulnerable to infection and further pest attack (Leefmans, 1923; Penatos & Ochoa, 1979, cited by Waterhouse & Norris, 1989); and (iii) when insufficient mature berries are available, i.e. at the beginning of the season or where frequent harvesting is practiced, the hard, green berries are attacked. Although unsuitable for breeding, the female beetle often makes abortive attempts to bore into these berries causing premature fall, arrested development or decay (Schmitzet & Crisinel, cited by Le Pelley, 1968; De Kraker, 1988; Ortiz-Persichino, 1991).

The lesions caused by the activity of the scolytid create an entry site for secondary infection by bacteria and fungi. Two species of bacteria, *Erwinia stewartii* (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). *Erwinia stewartii* has also been isolated from the exoskeleton of the scolytid, implying that it may be important in the spread of secondary infective agents and the subsequent losses resulting from its own abortive boring activities in immature berries. In the same study, various pathogenic and saprophytic organisms, including *Acremonium* sp., *Bacillus* sp., *Erwinia herbicola* (Löhnis) Dye and *Fusarium solani* (Mart.) Sacc. (Moniliales: Tuberculariaceae) were isolated from fresh *H. hampei*-infested berries and seeds, whereas from infested, processed beans, *Aspergillus niger* Tiegh. (Hyphomycetes: Hyphales), *Fusarium* sp., *Penicillium* sp., *Rhizopus* sp. and *Verticillium* sp. were isolated.

Biology and ecology of *H. hampei*

General characteristics of the Scolytidae

The family Scolytidae can be divided into two main subdivisions; the subcortical feeders or bark beetles and the woodborers or ambrosia beetles, which includes 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. The galleries carved out by scolytids (including those of *H. hampei* in coffee berries) are often stained blue by the presence of yeasts and other fungi, which may serve to attract other beetles and/or augment food quality when they are digested along with the phloem (Rudinsky, 1962; Mitton & Sturgeon, 1982). Sponagel (1994) observed that, in recent perforations in coffee berries, the typical blue-green stain of ambrosia fungi could be distinguished, but that the presence of the fungus was not obligatory for optimal larval development.

Biology and life cycle of H. hampei

The morphology and life cycle of *H. hampei* are described in detail by Leefmans (1923), Toledo-Piza-Junior (1928), Bergamin (1943), Schmitzet & Crisinel (1957), Ticheler (1961), Urbina (1987), Waterhouse & Norris (1989), Hill & Waller (1990), Baker *et al*. (1992a,b), Barrera (1994), Borbón-Martinez (1994) and Sponagel (1994). Briefly, 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 4 (egg), 15 (larva) and 7 (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 (Hargreaves, 1926). Nine generations per year of *H. hampei* are reported in the Ivory Coast, with a complete life cycle every 30 days. In Colombia, despite an extended cropping period, Montoya & Cardenas (1994) suggested that there were only two to three generations per year, confirmed by Baker (1998) who stated that *H. hampei* is not an explosive pest, having a relatively low r value.

According to Ticheler (1961), the wing muscles of the female degenerate when egg laying commences, preventing the colonization of more than one berry. Waterhouse & Norris (1989), however, suggested that the female may leave the berry when all the seed tissue is consumed or deteriorated in some way in order to continue egg-laying in another berry, or when her progeny begin to emerge. Due to the extended oviposition period of the female, all life stages of *H. hampei* can be found in the berry at the same time.

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 h (Sponagel, 1994). Infestation first occurs in berries attached to the bushes but reproduction continues in berries that subsequently fall to the ground and in processed berries, provided that humidity does not fall below 12.5% (*C.*

canephora) or 13.5% (*C. arabica*) (Hargreaves 1935, cited by Waterhouse & Norris, 1989). *Hypothenemus hampei* infestations tend to accumulate in aggregations or foci within trees and from there may extend to various coffee trees close together (Baker *et al*., 1984). Moore *et al*. (1990) considered the aggregation behaviour of bark beetles to be a response to host defences, mediated by pheromones, i.e. the need for a mass attack to overcome the defences of a vigorous host plant, as described by Rudinsky (1962). In scolytids such as *H. hampei* which attack fruits, however, this type of attack does not occur, but the tendency to aggregate continues with the formation of foci of infestation. Ochoa & Decazy (1987), working in Guatemala, mentioned that, at higher infestation levels (above 10%), distribution of the scolytid changed from aggregation to a more even distribution. Ten per cent is not, however, a particularly high level of infestation and the author has observed that the tendency to aggregate continues at all levels of infestation. The penetration of green berries may be a temporary deterrent to further boring activities in the vicinity and, therefore, act against the tendency to aggregate (De Kraker, 1988). This tendency to aggregate is a very important but poorly understood aspect of the biology of this pest.

The annual cycle of *H. hampei* infestation is very closely related to that of the coffee crop and more so where coffee production is of a markedly seasonal rather than continuous nature (Sponagel, 1994). In the interharvest 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 (Baker & Barrera, 1993). The rain itself is not the trigger, the coffee berries simply become waterlogged and uninhabitable (De Kraker, 1988).

An extended dry season can reduce *H. hampei* infestations due to the sensitivity of the scolytid to humidity levels (Baker *et al*., 1994). There was a suggestion that borers grouped together in large numbers during the inter-harvest period resisted desiccation, but the paper also mentions the possibility of some kind of brood hygiene at higher humidities, with excess and/or pathogen-infected individuals being pushed out of the berry. Survival and carry-over of the population is enhanced by reproduction in late berries and the ability to feed upon the early, immature berries of the new crop (Clausen, 1978; Baker *et al*., 1994). Up to 150 adults may be found in a single berry during the interharvest period, as reproduction continues until the resources are totally exhausted (Brocarta No. 3, 1993). Lavabre (1990) stated that in February, in the Ivory Coast, all *H. hampei* are adults (Lavabre, 1990). However, in a recent study, significant numbers of larvae and pupae were found in dissected coffee berries collected from the Ivory Coast at this time (Damon, 1999). Such stark differences in the literature suggest weaknesses in the methodology, changes induced by climatic or management factors or the divergence of *H. hampei* into races, with different characteristics in different areas. Corbett (1933, cited by Waterhouse & Norris, 1989) stated that a female *H. hampei* can 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).

Berries fallen to the soil suffer decomposition by bacteria, fungi and nematodes which may result in the death of the occupants or promote migration. The destruction of fallen coffee berries by bacteria and fungi make an important contribution towards the reduction of available food for the reproduction of the pest (Schmitzet & Crisinel, 1957; Klein-Koch *et al*., 1988).

Waterhouse & Norris (1989) mention that the first-stage larvae may begin feeding on frass; this may be a way of acquiring the symbiotic fungi often associated with scolytid beetles. The situation regarding *H. hampei* and fungal symbionts remains unclear, but attacked beans always have a distinct blue-green colour. Recently, *H. hampei* was found to carry *Fusarium solani* (Mort.) Sacc. (Moniliales: Tuberculariaceae) on cuticular hairs, suggesting a close association between fungus and scolytid (Rojas *et al*., 1999). This fungus is common and widespread and has been reported as symbiotically associated with other Scolytidae such as *Xyleborus ferrugineus* (Fabricius) (Baker & Norris, 1968).

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 (Giordanengo, 1992). Lopez & Frérot (1993) found in Colombia, that only 62% of female *H. hampei* leaving berries are fertilized, suggesting that, in contrast to other studies (e.g. Giordanengo, 1992; Baker, 1984), a significant proportion of *H. hampei* mate outside the berry in which they develop.

Decazy (1989) claimed that the majority of individual *H. hampei* fly very little, but a small proportion can travel long distances in search of new berries, often aided by air currents. Flight may be induced by various factors: the first rains following the inter-harvest period, the depletion or deterioration of food resources within the berry (overcrowding, waterlogging, rotting, etc.), or the search for a mate or berry suitable for oviposition (De Oliveira Filho, 1927). Although rain is one of the factors that induces females to fly, female *H. hampei* have not been observed to fly when it is actually raining (Hernández-Paz & Sanchez de Leon, 1972) and are usually reported to fly during mid- to late-afternoon (Corbett, 1933; Morallo-Rejesus & Baldos, 1980). 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). In Ecuador, *H. hampei* was seen to spread at a rate of 30–60 km per year (Sponagel, 1994).

Attraction of H. hampei *to coffee berries*

Analysis of the stimulus which attracts female *H. hampei* to coffee berries has produced conflicting results. Experiments by Prates (1969) showed that the scolytid was not attracted towards extracts of leaves or flowers. Experiments by Igboekwe (1984) and more recently, P. Baker (1999, personal communication) suggest that adult female *H. hampei* showed a significant preference for red over green berries, whereas Sponagel (1994) concluded that colour played no part in berry selection by the scolytid as a result of experimentation with non-organic colour traps. De Kraker (1988) found that emerging *H. hampei* did not show a convincing preference for green berries with an endosperm adequate for oviposition, i.e. with more than 20% dry weight. Lopez (1993) concluded that female *H. hampei* were equally attracted towards green and red berries and the scent of mature infested and uninfested coffee berries elicited a response in only 20% of trials. In these experiments, caffeine at 450 ppm was repellent and gave zero response at concentrations of 250 and 100 ppm. Giordanengo *et al*. (1993) showed that, in Petri-dish choice tests and y-tube olfactometers, very few female *H. hampei* could discriminate between berries at different ripening stages and that one of the factors behind this discrimination was one or more of the chemicals that could be extracted from the berries by acetone. More recent work done by Gutiérrez-Martinez & Ondarza (1996) suggested that caffeine may play an important role in the attraction of *H. hampei* to its host plant, but the results were inconclusive and it is probable that the ethanol and methanol-based solvents were the important components of the attraction, as caffeine is not a volatile substance. At present, the information is confusing and conflicting and cannot be used to design monitoring and control techniques, such as colour or kairomone traps.

Alternative hosts

A summary of the alternative hosts reported for *H. hampei* is presented in table 1. The majority of the reports relate to feeding only, but it is useful to note that *H. hampei* is not specific to coffee; plants from various families can provide appropriate conditions for reproduction of the pest. This could be an important factor in coffee producing areas where production is seasonal; the elimination of these alternative hosts, which may support carry-over populations of the pest between the coffee harvest and new crop, could contribute towards a reduction of infestation by *H. hampei*. No work has so far been done on the potential of alternative host plants (which could be could be regularly destroyed and replanted) to attract *H. hampei* away from the coffee crop. There are many reports of feeding, with occasional reproduction, in plants of the Fabaceae family. Some of these plants may fix nitrogen and serve the double purpose of improving soil fertility as well as acting as a lure for *H. hampei*.

Key ecological, management and economic factors

Mendez & 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).

The price of coffee plays an important role in the dynamics of infestations of *H. hampei*. When the price is good, harvesting tends to be almost complete, resulting in little or no carry over of the pest between seasons.

Hypothenemus hampei has been noted to preferentially attack smaller berries (Friederichs, 1924; also noted by the author) and those without a prominent calyx disc or scar are less susceptible to attack (Ticheler, 1961).

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).

Models have been produced to try and improve economic and ecological recommendations for the control of the pest, including these and other biological, agricultural, social and economic factors (Leach, 1998). The calculation of economic injury thresholds for *H. hampei* has been studied by various people (e.g. Decazy, 1990; Ortiz-Persichino, 1991; CIES, 1993) and work continues to develop sampling methods to improve efficiency and reduce environmental damage from the application of chemical control and towards improved integrated control techniques. However, Baker (1999b) commented that the complexity of the *H. hampei*–coffee–climate relationship really precludes the development of a simple, reliable sampling method to predict infestation levels and provide adequate economic threshold indicators for insecticide application.

In a recent summary of *H. hampei* research in Colombia, Baker (1999a,b) discounted farmer-based sampling as a viable tool for predicting infestation levels of the pest and the implementation of intergrated pest management. The results gave little more information than that gained by simple observation and farmers had problems with calculations, disliked the process and many showed disinterest in the adoption of the complete, recommended pest control package for which sampling is only the starting point.

Control methods for the coffee berry borer

The pros and cons of chemical control for H. hampei

The coffee berry borer is notoriously difficult to control, passing the entire life cycle hidden within the seed of the coffee berry. Eggs are laid within the berry and it is only when the adult female leaves the berry, typically at the end of the inter-harvest period to find and colonize a fresh berry, that the insect is exposed to contact chemical control. However, contact poisons tend not to penetrate the heavy carapace and stomach poisons, which might have been considered for use when females are just entering berries at the beginning of the season, are useless, because the female declines to eat the skin of the berry that is removed during boring.

The development of the relatively less toxic organochlorine, endosulfan, as an alternative to insecticides such as gamma HCH and dieldrin, caused a revolution and its use

Table 1. Alternative host plants of *Hypothenemus hampei.*

Specific name	Family	Reference	Reproduction reported	Feeding only reported
Coffea canephora Pierre ex. Fröhner.	Rubiaceae	[1], Le Pelley, 1968 Various authors	•	•
C. arabica L.				
C. *dewevrei*				
C. dybowski				
C. excelsa				
C. liberica W. Bull ex Hiern				
Ixora sp.	Rubiaceae	[1]	•	•
Psychotria luconiensis (Cham. & Schitdl.)	Rubiaceae	[1]	•	•
Oxyanthus sp.	Rubiaceae	[3], Decazy, 1990	•	•
Cleome rutidosperma DC.	Capparidaceae	[1]		•
Passiflora foetida L.	Passifloraceae	[1]		•
Rubus rosaeflorus Hook.	Rosaceae	[1]		•
Rubus sp.		[3]		•
Eriobotrya japonica (Thunb.)	Rosaceae	Urbina, 1987		
Zea mays L.	Poaceae	Urbina, 1987	•	
Cola sp.	Sterculiaceae	Friederichs, 1922		
Ricinus sp.	Euphorbiaceae	Urbina, 1987		•
Hibiscus sp.	Malvaceae	[3]		•
Gossypium hirsutum L.	Malvaceae	Urbina, 1987		
Dioscorea sp.	Dioscoreaceae	[1]	•	
Operculina turpethum (L.)	Convolvulaceae	[1]		•
Ligustrum pubinerve (?)	Oleaceae	[3]		•
Vitis lanceolaria (Roxb.) Wall.	Vitaceae	[3]		•
Dialium sp.	Fabaceae	Le Pelley, 1968	•	
Dialium lacourtianum De Wild ex. Vermoesen		Decazy, 1990	•	
Caesalpinia pulcherrima (L.) Sw.	Fabaceae	[1,3]		•
Cassia occidentalis L.	Fabaceae	[1]		•
Gliricidia sepium (Jacq.)	Fabaceae	[1]	•	•
Crotalaria juncea L.	Fabaceae	[1,3]		•
Centrosema plumieri (Pers.) Benth.	Fabaceae	[3]		•
C. pubescens Benth.		[1]		
Pisum sativum L.	Fabaceae	Urbina, 1987		
Phaseolus lunatus L.	Fabaceae	[1,3]		•
Cajanus cajan (L.) Millsp.	Fabaceae	Campos, 1991	•	
Tephrosia candida DC.	Fabaceae	[3]		•
Abrus precautorius L.	Fabaceae	[1]		•
Calapogonium mucunoides Desv.	Fabaceae	[1]		•
Pueraria phaseoloides (Roxb.) Benth.	Fabaceae	[1]		•
Arachis hypogaea L.	Fabaceae	Urbina, 1987		
Leucaena leucocephala (Lam.)	Fabaceae	[1,3]	•	•
L. glauca De Wit.				
Acacia ingrata Benth.	Fabaceae	[1]		•
Acacia decurrens Willd.		Urbina, 1987		
Mimosa pudica L.	Fabaceae	[1]		•

Taken from [1]Morallo-Rejesus & Baldos, 1980; [2]Johanneson & Mansingh, 1984; [3]Waterhouse & Norris, 1989.

continues to the present day as the most common chemical treatment for *H. hampei* (Waterhouse & Norris, 1989; Sponagel, 1994). However, resistance was reported in New Caledonia in 1987 (Brun & Ruiz, 1987) and later research showed that resistant female *H. hampei* from New Caledonia also tended to be resistant to other chemicals, especially other organochlorines, by the process of cross-resistance (Brun *et al.*, 1994). Metabolic resistance was not implicated; target site insensitivity or binding were considered more likely. No cross-resistance was reported to carbaryl or organophosphates. The tendency towards inbreeding of *H. hampei* was thought to contribute to insecticide resistance (Giordanengo, 1992). Comparisons between the action of pirimiphos-methyl and endosulfan in Togo revealed that neither insecticide had any effect whatsoever upon *H. hampei* hidden within overripe (black), coffee berries. On a positive note, in those tests pirimiphos-methyl and endosulfan did not affect any of the three commonest parasitiods, *Cephalonomia stephanoderis* Betrem, *Prorops nasuta* Waterston (Hymenoptera: Bethylidae) and *Phymastichus coffea* La Salle

(Hymenoptera: Eulophidae) (Decazy, 1991). A Colombian study, however, showed that the parasitoids were killed by applications of endosulfan (Guzman, 1996).

Sponagel (1994) demonstrated up to 79% control efficiency after six applications of Thiodan 350 g l^{-1} EC (endosulfan) at 1.5 kg ha^{-1} using 325 l of water. The insecticide also showed a marked and extended period of protection by repellency, during which female *H. hampei* made only brief attempts to perforate berries and then left; the pulp was only slightly damaged and perforations did not reach the seed. Endosulfan kills by fumigant action at high temperatures but, using fluorescent material, it was shown that the liquid also reached the galleries and there would probably act as a contact or food poison. The residual effect lasted for 7.5 months, suggesting possible contamination of the harvested product.

Manual and cultural control

Discussion of cultural techniques may be found in Solís-Morán (1986), Decazy (1989), Waterhouse & Norris (1989), Baker, (1999b), Damon (1999) and various publications by Cenicafé, the Columbian coffee research institute (e.g. 'Brocarta').

The modern version, 'repase' (passing over again) of the technique 'rampassen', originally presented by Friederichs (1922), involves the collection of every coffee berry of all possible stages from both the bushes and the ground, once, immediately after the harvest (Waterhouse & Norris, 1989). Hargreaves (1926) claimed this process to be counterproductive, as the practice of removing ripe and overripe berries takes a disproportionate toll on parasite populations. He reversed the recommendation, suggesting that ripe berries be left on the ground to ensure survival and multiplication of parasitoids. The author, however, considers that it would be pointless to risk leaving a burgeoning population of *H. hampei* in unharvested berries in order to maintain a parasitoid population that only very doubtfully would control 50%, let alone 100% of the pest and where regular and clean harvesting practices would in any case render the parasites totally unnecessary!

ISMAM (Indígenas de la Sierra Madre, Motozintla, Chiapas, Mexico) (1990) advise producers to collect and destroy all coffee berries resulting from premature, 'crazy' flowerings, so as to prevent *H. hampei* from gaining a foothold in these early berries. Teaching producers to record the major flowering date enables them to calculate the date on which first attacks by the scolytid are likely. From that, efficient and timely control measures can be taken (Decazy, 1996). Comments by Baker (1999a,b), however, suggest that the response of *H. hampei* to flowering times was not uniform and that this did not, therefore constitute an adequate management tool.

Sponagel (1994) evaluated the efficiency of frequent (every one to two weeks during peak periods and every two weeks at the beginning and end of the harvest period) and clean harvesting for the control of *H. hampei* and the results showed very little difference between the experimental plots and the uncontrolled producer's plots where harvesting was irregular and incomplete. He also found no significant difference between infestation levels in plantations with low planting density and little shade and those with high density and heavy shade.

Moderate pruning of shade trees and coffee bushes may be important as shade has been reported as unfavourable for natural enemies and coffee bushes are also made easier to harvest (Hargreaves, 1926; Kenya Coffee, 1992).

Although cultural control is currently the cheapest and most accessible control method for *H. hampei*, even these methods, being highly labour intensive, are not always practical or feasible and may not be cost-effective. Success, in any case, also depends upon the acceptance by the farmer of the proposed techniques (Baker, 1999b; Jiménez, 1999), the skill and dedication of the farmer and demands that outbreaks of *H. hampei* are controlled in neighbouring plantations at the same time (Baker, 1984).

Biotechnology

Some work has been done on resistance genes in plants that code for inhibitors of proteases, such as the enzymes trypsin and chemotrypsin. These enzymes degrade proteins in the digestive tract of insects. The presence of such inhibitors in the diet of pests such as *H. hampei* can retard growth and development and ultimately cause death. Work by Valencia *et al*. (1994) showed trypsin and chemotrypsin activity in larval *H. hampei* but little or no activity was detected in the adult stage. Trials with inhibitors of these two enzymes showed a significant effect over an extended period of time, which shows promise for the employment of this type of resistance in coffee (Valence *et al*., 1994).

Alternative products

In the ISMAM (1990) guide to organic coffee production, various herbal concoctions are recommended for control of *H. hampei*, including tobacco, leaves and tendrils of tomato, cloves of garlic and chilli; these are boiled in water, left to ferment for a few hours and then sprayed onto the coffee crop using plain soap as a wetting agent. They also claim that lime dust reduces the infestation but does not kill the pest. There are no data with which to evaluate these suggestions.

The seed of the neem tree, *Azadirachta indica* A. Juss. (Meliaceae), has strong insecticidal properties and is used on a commercial level in some crops. Schmutterer (1990) described neem, in which the main active ingredient is azadirachtin, as a medium to broad spectrum insecticide, with a repellent effect against phytophagous insects of most, if not all, insect orders. Applications of a 2.5% solution of pure neem oil (0.04% azadirachtin) in water at 8.1 l ha^{-1} achieved a mortality of 26% against *H. hampei* after three applications. In this case, no indication of repellency was observed. With neem oil enriched with azadirachtin to 0.2%, 65% mortality was observed after three applications and a repellent effect was noted, with up to 80% of the berries showing signs of having been rasped only superficially. Similar results were obtained using African palm oil (instead of neem oil) enriched with azadirachtin. Both substances were comparable in effect with endosulfan, but with the repellent effect of 40–50% shorter duration, therefore requiring twice as many applications. Nonetheless, neem is significantly more expensive than endosulfan (if the environmental costs are not included) unless cultivation and extraction are carried out on site. The main problem mentioned was the rapid biodegradation of azadirachtin in the field, giving a persistence of only a few days. Also, the effect is delayed, resulting in a period of continued (albeit reduced) feeding after application (Schmutterer, 1990).

Biological control

Various natural enemies, entomopathogens, parasitoids and nematodes that have been recorded from *H. hampei*, are listed in table 2. No forest scolytids were found to contain any viruses in a review by Mills (1983). As a cryptic species, *H. hampei* is well protected from predation and parasitism and is listed in the category of insects with the smallest complex of parasites and predators (Hawkins *et al*., 1993).

Entomopathogens

Beauveria bassiana (Vuillemin) (Deuteromycetes) is present throughout the world in various climatic zones and has been found to attack 200 or more species of insect with a predominance for Coleoptera, Lepidoptera, Auchenorrhyncha, Sternorrhyncha and Heteroptera (Sponagel, 1994). *Beauveria bassiana* exclusively attacks adult *H. hampei* and infection can be detected by a blob of white, cotton-wool like mycelium, growing away from the body of the insect, appearing at the entrance of the tunnel (perforation) bored into the coffee berry. Natural infestations are common and epizootics may occur, especially on the ground in cool conditions with high relative humidity and heavy shade.

Beauveria bassiana can be applied most effectively when female *H. hampei* are just starting to penetrate the berries at the beginning of the year, which usually coincides with the beginning of the rainy season and later during harvesting, when the pest may be forced to migrate to new berries (Brocarta No. 18, 1993). Applications are made early in the morning to ensure at least 6 h exposure before rain (De la Rosa-Reyes & Barrera, 1997). The low atmospheric humidity characteristic of the interharvest period prevents the use of *B. bassiana* for the control of the residual pest population, present in unharvested berries.

Experiments with a strain of *B. bassiana* in Ecuador revealed a notable virulence under controlled conditions but no difference between control and experimental plots in the field (Sponagel, 1994). Baker (1999a,b) concluded that applications of *B. bassiana* were uneconomic and should not be recommended until formulation problems had been resolved.

Insect natural enemies of H. hampei

Various insects, native to areas where coffee is an exotic crop, such as Colombia, have extended their dietary range to include the coffee berry borer in their diet (table 2). In Soconusco, Chiapas, Mexico, *Cephalonomia* sp. near *waterstoni* (Hymenoptera: Bethylidae), apparently native to the area has been found parasitizing the coffee berry borer (Pérez-Lachaud, 1998). Two unidentified parasitoids belonging to the families Braconidae and Encyrtidae were found parasitizing the larvae of *H. hampei* in the Philippines (Morallo-Rejesus & Baldos, 1980; Waterhouse & Norris, 1989).

In Uganda, *H. hampei* was reported to be brought under control during April by *Prorops nasuta* Waterston (Hymenoptera: Bethylidae), ovipositing on the full-grown larvae, followed, in July, by an unnamed parasitoid which apparently achieved even greater control (Hargreaves, 1924). The unnamed parasitoid was probably *Heterospilus coffeicola* Schmeid (Hymenoptera: Braconidae), as no other parasitoid has been found in the area. Work is currently being done on this insect which was collected during recent explorations in Uganda (USDA/EBCL, personal communication). During these recent explorations in East and West Africa, it has become clear that in some parts of Ethiopia, *H. hampei* is not a problem possibly due to an efficient parasitoid and/or predator complex, resistant strains of coffee or the exceptionally clean harvest, reducing pest carry over during the inter-harvest period (Damon, 1999). Very recently, *H. hampei* was found in the south and south-east of Ethiopia associated with three unidentified parasitoids, two attacking the larval stage and one the adult stage (Abebe, 1998). It was reported that there were no effective, indigenous natural enemies of the coffee berry borer in Kenya (Kenya Coffee, 1992).

Three parasitoids are found together in West Africa, *Cephalonomia stephanoderis* Betrem (Hymenoptera: Bethylidae), *P. nasuta* and *Phymastichus coffea* LaSalle (Hymenoptera: Eulophidae). Ticheler (1961), Idown (1980), Klein-Koch *et al*. (1988) and Lavabre (1990), considered *C. stephanoderis* to be the most important parasitoid of *H. hampei* in West Africa, acting mainly on populations of the scolytid in the black (over-ripe) berries left behind after the harvest. Ticheler (1961), Ingram (cited by Le Pelley (1968)), Koch (1973) and Klein-Koch *et al*. (1988), however, concluded that, although parasitoid-induced mortality may be considerable during the post-harvest period (black, over-ripe berries), the net effect upon *H. hampei* was slight. Recently, as a result of the use of a simulation model including pest, host plant and parasitoids, *P. coffea* was cited by Gutiérrez *et al*. (1998) as the only one of the three parasitoids that would be capable of lowering *H. hampei* populations in the field.

In the many reports on the performance of *C. stephanoderis* and *P. nasuta* (summarized by Damon, 1999), methods of estimating 'efficiency' and percentage parasitism differed considerably. Even basic survival could not be assumed, parasitoids from many releases simply died out, either immediately or within the first two or three months. Many releases were carried out during the dry season, with the intention of reducing residual populations of *H. hampei* surviving in the few unharvested berries hanging upon the trees or on the ground. These parasitoids then died out either during the onset of the rainy season, or due to the lack of *H. hampei* (Carrillo & Campos, 1991; Vega *et al*., 1991; Sponagel, 1994; Damon, 1999). Many authors reported that although estimates of parasitism (up to 80%, Barrera, 1989), mortality (up to 95%, all life stages, Benavides *et al*., 1994) and 'efficiency' were relatively high, that overall, the plots showed no statistical difference in infestation levels before and after parasitoid release and little or no difference between nearby plots where releases had not been carried out, e.g. Barrera (1989), Benavides *et al*. (1994) and Dufour *et al*. (1995).

By 1995, 227 million parasitoids had been released in Colombian coffee plantations (Orozco, 1995) but the overall conclusion of CENICAFÉ is that although *C. stephanoderis* does contribute towards the control of *H. hampei*, and may, under certain cirmumstances, prove to be as efficient as *B. bassiana* and endosulfan (Aristizábal, 1995) it could not be considered currently as an efficient and economically viable option (Baker, 1999a,b).

Table 2. Natural enemies of the coffee berry borer.

Group and species	Country	Reference	Comments
Aves			
Swallows	Java	Leefmans (1923)	Presumably catches flying adult female *H. hampei*
Reptilia			
Various		[2]	
Hymenoptera			
Bethylidae			All ectoparasites of immature stages
Cephalonomia stephanoderis Betrem	Ivory Coast Togo Cameroun Congo Zaire	[2]; Ticheler, 1961; Moore & Prior, 1988	
Cephalonomia sp.	Mexico	Pérez-Lachaud, 1998	
Cephalonomia sp.	Brazil	Benassi & Perti-Filho, 1989	
Prorops nasuta Waterston	Kenya Tanzania Togo Uganda Cameroun Ivory Coast Zaire Congo	[2]; Rangi *et al.*, 1989; Moore & Prior, 1988; Ticheler, 1961; Le Pelley, 1968; Klein-Koch *et al.*, 1988	
Scleroderma cadavericus Benoit	Uganda Kenya	[1]	(Contact provokes severe dermatitis in man)
Eulophidae			
Tetrastichus sp. (later, *Phymasticus coffea* (La Salle))	Togo	Klein-Koch *et al.*, 1988	Attacks adult *H. hampei*
Phymasticus coffea (La Salle)	Kenya	Moore (unpublished)	
Braconidae			
Heterospilus coffeicola Schmiedeknecht	Uganda Zaire Kenya Tanzania Cameroun	2; Le Pelley, 1968; Klein-Koch *et al.*, 1988	Feeds upon larvae and larval parasitoids of *H. hampei* May be cannibalistic
Unidentified	Philippines	Morallo-Rejesus & Baldos, 1980	Larval parasitoid
Close to *Cryptoxilos* sp.	Colombia	Cenicafé	
Exyntidae			
Unidentified (later identified as Encyrtidae)	Philippines	[1]; Morallo-Rejesus & Baldos, 1980	Larval parasitoid
Formicidae			
Crematogaster curvispinosa (Mayr.)	Brazil	[2]	Predator
Crematogaster sp.	Colombia		
Coleoptera			
Cathartus quadricularis (Guerin-Meneville)	Togo	Damon, 1999	Predator. Attacks eggs and small larvae.
Lepidoptera	Brazil	[1]	Caterpillars feed on the endosperm of the coffee seed, disturbing and successfully out-competing *H. hampei*
Blastobasidae			
Auximobasis coffeaella Busck.			
Hemiptera			
Pyrrhocoridae		[2]	
Dindymus rubiginosus (Fabricius)	Java		Not specific
Nematoda			
Heterorhabditis sp.	?	[2]; Moore & Prior, 1988	Kills larval and adult *H. hampei* and can complete its life cycle in adults and older larvae.
Protozoa			
Microsporidia close to *Mattesia* sp.	Colombia	Cenicafé (A. Bustillo, personal communication)	
Bacteria			
Bacillus sp.	Colombia	Cenicafé (A. Bustillo, personal communication)	
Serratia sp.	Colombia		

Table 2. Continued

Group and species	Country	Reference	Comments
Fungi			
Hyphomycetes			
Beauveria bassiana Vuillermin	Java Brazil Cameroun Indonesia Ecuador Colombia Kenya, Mexico Nicaragua, Togo Thailand	[2]; Klein-Koch *et al.*, 1988, Bustillo, 1991	Cosmoplitan, various strains, various hosts.
B. brongniartii Sacc. (Petch)	Colombia Colombia Brazil	Moore & Prior, 1988	
Metarhizium anisoplia (Metschn.) Sorokin	?	[2]; Le Pelley, 1968	
Nomurea rileyi (Farlow)	Java Indonesia	[2]; Moore & Prior, 1988	Usually recorded from Lepidoptera
Paecilomyces javanica (=*Spicaria javanica*)	Colombia	[2]	On larvae inside blackened berries.
P. tenuipes	Colombia	Posada-Flóres *et al.*, 1998	
P. lilacinus	Colombia	Posada-Flóres *et al.*, 1998	
Fusarium sp.	Colombia	Posada-Flóres *et al.*, 1998	
Hirsutella eleutheratorum (Nees) Petch	Colombia	Posada-Flóres *et al.*, 1998	

Taken from [1]Waterhouse & Norris, 1989; [2]Murphy & Moore, 1990; plus additions.

Damon (1999) showed that although releases of *C. stephanoderis* in the form of parasitized berries were up to five times more efficient than the traditional techniques of releases of emerged, collected adults, the impact of *C. stephanoderis* on the coffee berry borer in the field and in entomological cages remained low. The results demonstrated that the key problem with the use of this bethylid to control *H. hampei* was that the vast majority (63–96%) of the parasitoids released never 'found' a pest-infested berry. To compensate for the large proportion of ineffective parasitoids, very large numbers of insects would have to be released in order to register an effect upon the pest population.

Klein-Koch (1989) cited research by Patiño in which a strain of *P. nasuta* from Togo proved to be more efficient than the insects collected from Kenya. Moore *et al.* (1990) suggested extending the genetic base of the potentially highly inbred bethylids. In general, in the case of parasitoids, too little attention has been paid to the gathering of ecological data; several failures of classical biological control have been documented in which the inadequate fulfilment of ecological requirements was the key factor.

It has been shown that certain parasitoids and predators of scolytids have evolved to respond to the same aggregation pheromones as their host. Mitton & Sturgeon (1982) give examples of hymenopterans of the families Braconidae, Eulophidae and Pteromalidae which respond to such pheromones, both natural and synthetic. A possible drawback of using pheromone traps for the pest is that natural enemies might also be killed. Marked similarities are reported between complexes of the natural enemies associated with bark beetles in different parts of the world. As commented on in the literature (e.g. Hawkins, 1994), bark beetles and other insects with cryptic habits have far fewer natural enemies than defoliators and other external feeders. Parasitoids of bark beetles appear to be attracted to host plant odours rather than odours emanating from the beetle itself and are, therefore, more likely to parasitize various beetle species in one host tree species than follow a single beetle across its complete host plant range. Parasitoids in this protected environment tend to be ectoparasites. Parasitism is reported as low, often with no response to host density and unlikely to have an impact upon the host population.

Conclusions

Analysis of the case history of the coffee berry borer highlights the lack of coordination between interested parties in coffee-producing areas and the lack of a global strategy which would include improved quarantine procedures, a widening of research activity to include one or more of the novel aspects mentioned in this review and adequate technology transfer. All control strategies and intregrated control packages should be geared to the economic and ecological conditions of the different coffee-growing areas.

Biological control using parasitoids and entomopathogens has so far given disappointing results and *H. hampei* does not in any case have a wide selection of natural enemies. Hopes rest with *Phymasticus coffea* and *Heterospilus coffeicola* or some new natural enemy, such as *Cathartus quadricollis* (Guérin-Menéville) (Coleoptera: Cucujidae) which was observed feeding upon larvae of *H. hampei* in Togo (G. Mercadier, personal communication; Damon, 1999) as the only known natural enemies still to be evaluated fully.

Cultural control is as yet the safest, simplest and most accessible control method, especially for the thousands of small producers. It is labour intensive, however, depending upon cheap or free family labour in order to be cost-effective. Its application and efficiency depend very much upon adequate technology transfer and the dedication and skill of the producer and may be hindered by poor maintenance and the steep slopes which are frequently the only plots available to marginalized farmers.

Based upon the data presented here, the following aspects are recommended for further research. The suggestions are presented in order of priority, based upon the simplicity and low cost of the work involved and the likelihood of a favourable result. The author feels that suggestions 1 and 2 present the quickest route towards the development of a safe, easy to use, environmentally-friendly, farmer-friendly and widely applicable control method for *H. hampei*.

1. Detailed investigation on the chemical compounds produced by coffee (berries and/or bush), that attract *H. hampei* and the development of a species-specific trap, using these substances.
2. Detailed investigation of the pheromones or kairomones involved in the aggregation behaviour of *H. hampei* and the development of traps using these substances.
3. Research into the application of saprophytic or pathogenic microorganisms to degrade coffee berries on the ground, which harbour *H. hampei* during the interharvest period. (A product based on such microorganisms could have a negative effect upon soil microfauna.)
4. Detailed investigation upon the possible symbiotic relationship between the coffee berry borer and fungi. If a level of dependence is discovered, the interruption of this relationship could be a useful tool for control of the pest.
5. The use of alternative host plants (table 1) as trap crops. The success of such a method, were one developed, would depend upon the ability of the farmer to remove and destroy the trap crop at the appropiate time, to prevent recontamination of the coffee crop.
6. A clear analysis of environmental and management factors that influence infestation levels of *H. hampei* in different parts of the world. The incorporation of useful aspects into integrated pest management strategies geared to regional conditions.
7. Modelling, using these environmental factors, as a decision-making tool (Leach, 1998; Baker, 1999a,b) for safer use of chemical control and for the development of IPM strategies.
8. The possibility of the use of water to stimulate premature emergence, which would be followed by the death of the coffee berry borer during the interharvest period. This would obviously only be feasible and economically viable in certain areas.
9. The selection of morphological features of the coffee berry (e.g. less prominent calyx disc) which deter the boring activities of female *H. hampei*, without destroying the aroma and taste of the commercialized product.

References

Abebe, M. (1998) Further evidence on the occurrence of coffee berry borer in Ethiopia. Abstracts of the *Second Intercontinental Conference on Coffee Berry Borer. Tapachula, Mexico*. pp. 75–76.

Aristizábal, L.F. (1995) *Efecto del parasitoide* Cephalonomia stephanoderis *(Betrem) (Hymenoptera: Bethylidae) sobre una población de* Hypothenemus hampei *(Coleoptera: Scolytidae) en condiciones de campo*. 129 pp. BSc thesis, University of Caldas, Colombia.

Baker, J.M. & Norris, D.M. (1968). A complex of fungi mutualistically involved in the nutrition of the ambrosia beetle *Xyloborus ferrugineus*. *Journal of Invertebrate Pathology* **11**, 246–250.

Baker, P.S. (1984) Some aspects of the behaviour of the coffee berry borer in relation to its control in southern Mexico (Coleoptera: Scolytidae). *Folia Entomológica Mexicana* **61**, 9–24.

Baker, P.S. (1998) The biology, ecology and behaviour of the coffee berry borer and its parasitoids. *Second International Conference on Coffee Berry Borer. Tapachula, Mexico*. p. 64.

Baker, P.S. (1999a) Colombian coffee IPM. *Biocontrol News and Information* **20**, 72–73.

Baker, P.S. (1999b) *The coffee berry borer in Colombia*. DFID-Cenicafé-CABI Bioscience, Feriva S.A.

Baker, P.S. & Barrera, J.F. (1993) A field study of a population of Coffee Berry Borer, *Hypothenemus hampei* (Coleoptera: Scolytidae), in Chiapas, Mexico. *Tropical Agriculture (Trinidad)* **70**, 351–355.

Baker, P.S., Barrera, J.F. & Valenzuela, J.E. (1989) The distribution of the coffee berry borer (*Hypothenemus hampei*) in southern Mexico: a survey for a biocontrol project. *Tropical Pest Management* **35**, 163–168.

Baker, P.S., Barrera, J.F. & Rivas, A. (1992a) Life history studies on the coffee berry borer (*Hypothenemus hampei*, Scolytidae) on coffee trees in southern Mexico. *Journal of Applied Ecology* **29**, 656–662.

Baker, P.S., Barrera J.F. & Rivas, A. (1992b) Factors affecting the emergence of *Hypothenemus hampei* (Coleoptera: Scolytidae) from coffee berries. *Bulletin of Entomological Research* **82**, 145–150.

Baker, P.S., Rivas, A., Balbuena, R., Ley, C. & Barrera, J.F. (1994) Abiotic mortality factors of the coffee berry borer (*Hypothenemus hampei*; Coleoptera, Scolytidae). *Entomologia Experimentalis et Applicata* **71**, 201–209.

Barrera, J.F. (1989) Informe técnico. Proyecto 'Control Biológico de la Broca del Cafeto'. *Promecafé*, P218CC0C8860837.

Barrera, J.F. (1994) *Dynamique des populations du scolyte des fruits du caféier,* Hypothenemus hampei *(Coleoptera: Scolytidae), et lutte biologique avec le parasitoide* Cephalonomia stephanoderis *(Hymenoptera: Bethylidae), au Chiapas, Mexique*. 301 pp. PhD thesis, Université Paul-Sabatier, Toulouse III, France.

Barrera, J.F., Baker, P.S., Schwarz, A. & Valenzuela, J.E. (1990) Introducción de dos especies de parasitoides africanos a México para el control biológico de la broca del café *Hypothenemus hampei* (Ferrari) (Coleoptera: Scolytidae). *Folia Entomológica Mexicana* **79**, 245–247.

Benassi, V.L.R.M. & Berti-Filho, E. (1989) Nota sobre la ocurrencia de *Cephalonomia* sp. (Hymenoptera: Bethylidae) parasitando a broca-do-café, *Hypothenemus hampei* (Ferrari, 1867) (Coleoptera: Scolytidae) no Estado do Espirito-Santo. *Revista de Agricultura* **64**, 105–106.

Benavides, P., Bustillo, A.E. & Montoya, E.C. (1994) Avances sobre el uso del parasitoide *Cephalonomia stephanoderis* para el control de la broca del café, *Hypothenemus hampei*. *Revista Colombiana de Entomología* **20**, 247–253.

Bergamin J. (1943) Contribucao para o conhecimiento da biología da broca do café *Hypothenemus hampei* (Ferrari, 1867) (Col: Ipidae). *Archives of the Institute of Biology* **14**, 31–72.

Borbón-Martinez, O. (1994) *Uso de control biológico de la broca del cafeto* Hypothenemus hampei *Ferrari 1867*. 23 pp. Report, Institut de Recherche de Café y Cacao, Kpalimé, Togo.

Brocarta, No. 3, 17, 18. (1993) *Cenicafé*. Chinchiná, Colombia.

Brun L.A. & Ruiz, J.L. (1987) Detection of endosulphan resistance in coffee berry borer *Hypothenemus hampei* Ferr. (Coleoptera: Scolytidae) in New Caledonia. *International Conference on Pesticides in Tropical Agriculture. Kuala Lumpur.*

Brun, L.A., Marcillaud, C. & Gaudichon, V. (1994) Cross resistance between insecticides in coffee berry borer, *Hypothenemus hampei* (Coleoptera: Scolytidae) from New Caledonia. *Bulletin of Entomological Research* **84**, 175–178.

Bustillo, A.E. (1991) La broca del café en Colombia y sus posibilidades de conrolarla biologicamente. *Revista da la Facultad de Ingeneria Agronomica (Ibagué)* Año **2**, 33–34.

Campos, O.G. (1991) El gandul *Cajanus cajan* como hospedero de la broca del fruto del cafe *Hypothenemus hampei* (Ferrari 1867) en Guatemala. *Revista Cafetalera de Guatemala* **231**, 4–9.

Carrillo, E. & Campos, O.G. (1991) La broca del café en Guatemala. pp. 24–25 in *Resumenes: I Reunión intercontinental sobre la broca del café.*

CIES (1993) *Guía practica: Umbrales econoómicos para el control de la broca del café.* 49 pp. Secretaria de desarrollo rural y ecología.

Clausen, C.P. (1978) *Introduced parasites and predators of arthropod pests and weeds: a world review.* pp. 292–294. Agriculture Handbook No. 48. ARS, USDA. Washington DC.

Corbett, G.H. (1933) Some preliminary observations on the coffee berry beetle borer *Stephanoderes* (*Cryphalus) hampei* Ferr. *Malay Agriculture Journal* **21**, 8–22.

Damon, A.A. (1999) *Evaluation of current techniques and new approaches in the use of* Cephalonomia stephanoderis *(Hymenoptera: Bethylidae) as a biological control agent of the coffee berry borer,* Hypothenemus hampei *(Coleoptera. Scolytidae), in Chiapas, Mexico.* PhD thesis, University of London.

Davidson, A. (1967) The ocurrence of coffee berry borer *Hypothenemus* (*Stephanoderis*) *hampei* in Ethiopia. *Café* **8**, 1–3.

Decazy, B. (1989) Le scolyte du fruit du caféier, *Hypothenemus hampei*: considérations sur la lutte intégrée contre ce ravageur. *ASIC, 13 Colloque, Paipa.* pp. 655–665.

Decazy, B. (1990) Consideraciones sobre el uso apropiado del control químico de la broca del fruto del cafeto *Hypothenemus hampei* Ferr. pp. 125–128 in *IICA/Promecafé. Resumenes: III Taller regional de broca.*

Decazy, B. (1991) *Investigaciones conducidas en Francia y Africa sobre la broca del fruto del cafeto* Hypothenemus hampei *Ferr. (Scolytidae, Coleoptera).* 13 pp. Unpublished report, CIRAD/IRCC, Montpellier, France.

Decazy, B. (1992) Report of the Mission to Togo. *CIRAD-IRCC, Montpellier, France.* pp. 5–25.

Decazy, B. (1996) *Phénologie du fruit du caféier en relation avec l'infestation de* Hypothenemus hampei *Ferr. Actes des 5 journées de groupe de travaille relations insectes-plantes.* CIRAD-CA. Montpellier, France. pp. 55–56.

De Kraker, J. (1988) The coffee berry borer *Hypothenemus hampei* (Ferr.): factors affecting emergence and early infestation. Report of field experiments. *Centro de Investigaciones Ecologicas del Sureste*, Tapachula. 48 pp.

De Oliveira-Filho, M.L. (1927) Contribucao para o conhecimento da broca do café, *Stephanoderes hampei* (Ferr. 1867) modo de comportarse e ser combatida em Sao Paulo, Brasil. *Commissao do Estudo e Debellacao da Praga Caffeira. Sao Paulo* **20**, 1–95.

De-la Rosa-Reyes, W. & Barrera, J.F. (1997) *Guía practica: propagación masiva del hongo* Beauveria bassiana *para el combate biológico de la broca del café.* 23 pp. ECOSUR. Tapachula, Mexico.

Dufour, B., Calderon, S., Bernadette, L. & Aragon, F. (1995) *Control biológico de la broca del cafeto con* Cephalonomia stephanoderis *Betrem.* XVII Simposio sobre la Cafeticultura Latinoamericana, El Salvador. p. 7.

Friederichs, K. (1922) Measures against the coffee berry borer on the Karang Redjo Estate. *Meded. Van h. Koffiebessenboeboek-Fonds, Soerabaya* **1**, 1–22.

Friederichs, K. (1924) To what degree do differences exist in the susceptibility of varieties of coffee to the coffee berry borer *? Meded. Koffiebessenboeboek-Fonds* **11**, 315–318.

Giordenango, P. (1992) *Biology, eco-ethology and population dynamics of the coffee berry borer,* Hypothenemus hampei *Ferr. (Coleoptera. Scolytidae), in New Caledonia.* 109 pp. PhD thesis, University of Rennes II, France.

Giordanengo, P., Brun, L.O. & Frerot, B. (1993) Evidence for the allelochemical attraction of the coffee berry borer *Hypothenemus hampei* by coffee berries. *Journal of Chemical Ecology* **19**, 763–769.

Gutiérrez-Martinez A. & Ondarza, R.N. (1996) Kairomone effects of extracts from *Coffea canephora* over *Hypothenemus hampei* (Coleoptera: Scolytidae*). Environmental Entomology* **25**, 96–100.

Gutiérrez, A.P., Villacorta, A., Cure, J.R. & Ellis, C.K. (1998) A tritrophic analysis of the coffee (*Coffea arabica*) – coffee berry borer (*Hypothenemus hampei* (Ferrari)) – parasitoid system. *Second Intercontinental Conference on Coffee Berry Borer. Tapachula, Mexico.* pp. 41–42.

Guzman, E.D.B. (1996) *Efecto de varios insecticidas sobre el parasitoide de la broca del cafe* Cephalonomia stephanoderis. 131 pp. BSc thesis, Universidad de Caldas, Manizales, Colombia Facultad de Ciencias Agropecuarias.

Hargreaves, H. (1924) Annual Report of the Governmental Entomologist. *Uganda Department of Agriculture Annual Report 1924.* pp. 15–21. Entebbe.

Hargreaves, H. (1926) Notes on the coffee berry borer (*Stephanoderes hampei,* Ferr.). *Uganda Bulletin of Entomological Research* **16**, 347–354.

Hargreaves, H. (1935) *Stephanoderes hampei* Ferr., coffee berry borer in Uganda. *East Africa Agriculture Journal* **1**, 218–224.

Hawkins, B.A. (1994) *Pattern and process in host–parasitoid interactions.* 190 pp. Cambridge University Press.

Hawkins, B.A., Thomas, M.B. & Hochberg, M.E. (1993) Refuge theory and biological control. *Science* **262**, 1429–1432.

Hernández-Paz, M. & Sanchez de Leon, A. (1972) La broca del fruto del café. *Asociación Nacional del Café* **11**, 1–72.

Hill, D.S. & Waller, J.M. (1990) *Pests and diseases of tropical crops.* pp. 137–138 *in* Smith, N. (*Ed.*) Intermediate Tropical Agriculture Series, Longman, Singapore.

Idown, O.L. (1980) Comparative survival of the coffee berry borer, *Hypothenemus* (*Stephanoderis) hampei* (Ferr.) under two microhabitats of *Coffea canephora* in southern Nigeria. *ASIC. 9^{e} Colloque, London.*

Igboekwe, A.D. (1984) Preference of *Stephanoderis hampei* Ferrari to coffee berries of different developmental stages. *Indian Journal of Agricultural Science* **54**, 520–521.

ISMAM (1990) *Manual practico del cultivo biologico del café orgánico.* 333 pp. Holland, SOS Wereldhandel.

Jiménez, L. (1999) *Small-scale coffee growers knowledge and activities related to control of the coffee berry borer in Chiapas, Mexico.* 31 pp. MSc thesis, ECOSUR, Tapachula, Mexico.

Johanneson, N.E. & Mansingh, A. (1984) Host–pest relationship of the genus *Hypothenemus* (Coleoptera: Scolytidae) with special reference to the coffee berry borer, *H. hampei. Journal of Coffee Research* **14**, 43–56.

Kenya Coffee, Technical circular No. 174 (1992) Control of *Hypothenemus hampei* (Ferrari). *Kenya Coffee* **57**. No. 668.

Klein-Koch, C., Espinoza, O., Tandazo, A., Cisneros, P. & Delgado, D. (1988) Factores naturales de regulación y control biológico de la broca del café (*Hypothenemus hampei* Ferr.). *Sanidad Vegetal* **3**, 5–30.

Klein-Koch, C. (1989) Perspectivas en el control biotecnológico de la broca del café (*Hypothenemus hampei* Ferr.). *ASIC, 13^{e} Colloque, Paipa*. pp. 717–725.

Koch, V.J.M. (1973) Abundance of *Hypothenemus hampei* Ferr., the coffee berry borer, in relation to its food plant and its parasite *Cephalonomia stephanoderis* Betrem, in the Ivory Coast. *Mededelingen Landbouwhogeschool Wageningen* **73**, 1–84.

Lavabre (1990) Notes sur l'influence de facteurs biotiques et abiotiques sur les poblaciones d'*Hypothenemus hampei.* Conseiller Scientifique d'IRCC. Centre de Coopération Internacionale en Recherche Agronomique pour le Dévéloppment, France.

Leach, A. (1998) A simulation model for improved ecological and economic recommendations for the control of the coffee berry borer in Mexican coffee. *Second Intercontinental Conference on Coffee Berry Borer, Tapachula, Mexico*. pp. 71–72.

Leefmans, S. (1923) The coffee berry borer, *S. hampei*. I. Life history and ecology. *Meded. Inst. Plantenzieken* **57**, 61–67.

Le Pelley, R.H. (1968) *Las plagas del cafeto*. Editorial Labor S.A. Barcelona. 693 pp.

Lopez, A. (1993) *Reporte de pasantia*. Montpellier, France. IRCC/CIRAD. 30 pp.

Lopez, A. & Frérot, B. (1993) Statut physiologique des femelles colonisatrices de *Hypothenemus hampei* (Ferr.). *ASIC. 15 Colloque, Montpellier, France*.

Mendez, I. & Velasco, H. (1987) Infestación y daño de la broca *Hypothenemus hampei* Ferr. del fruto del cafeto en la Costa de Chiapas. *II Taller International sobre la Broca del Grano del Café. Tapachula, Mexico*. pp. 148–160.

Mills, N.J. (1983) The natural enemies of scolytids infesting conifer bark in Europe in relation to the biological control of *Dendroctonus* sp. in Canada. *Biocontrol News and Information* **4**, 305–328.

Mitton, J.B. & Sturgeon, K.B. (Eds) (1982) *Bark beetles in North American conifers*. 527 pp. USA, University of Texas Press.

Montoya, S.A. & Cárdenas-Murillo, R. (1994) Biologia de *Hypothenemus hampei* (Ferrari) en frutos de café de diferentes edades. *Cenicafé* **45**, 5–13.

Moore, D. & Prior, C. (1988) Present status of biological control of the coffee berry borer *Hypothenemus hampei*. *Proceedings of the Brighton Crop Protection Conference – Pests and Diseases*, pp. 1119–1124.

Moore, D., Abraham, Y.J. & Mills, N.J. (1990) Effects of competition in the coffee berry borer, *Hypothenemus hampei* (Ferrari) (Col. Scolytidae). *Journal of Applied Entomology* **109**, 64–70.

Morallo-Rejesus, B. & Baldos, E. (1980) The biology of the coffee berry borer *Hypothenemus hampei* (Ferr.) (Scolytidae: Coleoptera) and its incidence in the southern Tagalog provinces. *Philippine Entomologist* 4, 303–316.

Muñoz, R.I., Andino, A. & Zelaya, R. (1987) Fluctuación poblacional de la broca del fruto del café (*Hypothenemus hampei* Ferr.) en la zona de la Yojoa. *II Taller International sobre la Broca del Grano del Café. Tapachula, Mexico*. pp. 75–99.

Murphy, S.T. & Moore, D. (1990) Biological control of the coffee berry borer, *Hypothenemus hampei*, (Ferrari) (Coleoptera: Scolytida): previous programmes and possibilities for the future. *Biocontrol News and Information* **11**, 107–117.

Ochoa, H. & Decazy, B. (1987) Estudio de un tipo de muestreo para determinar el indice de combate de la broca del café. *II Taller International sobre la Broca del Grano del Café. Tapachula, Mexico*. pp. 44–68.

Orozco, H. (1995) Uso de parasitoides de origen africano para el manejo de la broca del café en Colombia. *Congreso Colombiano de Entomología. Santa Fé de Bogatá*. pp. 102–108.

Ortiz-Persichino, C. (1991) *Pérdidas por la broca del café en el Soconusco, Chiapas*. Informe técnico. Unidad de Estudios Economicos y Sociales, Centro de Investigaciones Ecológicas del Sureste, San Cristóbal de las Casas, Chiapas, Mexico. 126 pp.

Penatos Robles, R. & Ochoa Milan, H. (1979) La consistencia del fruto del café y su importancia en el control de broca. *Revista Cafetalera* **181**, 11–16.

Pérez-Lachaud, G. (1998) A new bethylid attacking the coffee berry borer in Chiapas (Mexico) and some notes on its biology. *Southwestern Entomologist* **23**, 287–288.

Posada-Flóres, F.J., Marí-Marín, P. & Pérez-Sierra, M. (1998) *Paecilomyces lilacinus*, enemigo natural de adultos de *Hypothenemus hampei*. *Cenicafé* **49**, 72–77.

Prates, H.S. (1969) Observacoes preliminares da atracao da broca do café *Hypothenemus hampei* (Ferrari, 1867), a extratos de frutos do caféeiro (cereja e verde). *O Solo* **61**, 13–14.

Purseglove, J.W. (1968) *Tropical crops: dicotyledons*. pp. 458–488. Longman Scientific and Technical.

Rangi, D.C., Murphy, S.T., Nan'gayo, F.L. & Moore, D. (1989) Biological control of the coffee berry borer in Mexico. Fourth and Final Report. 23 pp. CAB International Institute of Biological Control. Unpublished.

Rojas, M.G., Morales-Ramos, J.A. & Harrington, T.C. (1999) Association between the Coffee Berry Borer, *Hypothenemus hampei* (Coleoptera: Scolytidae) and *Fusarium solani* (Moniliales: Tuberculariaceae). *Annals of the Entomological Society of America* **92**, 98–100.

Rudinsky, J.A. (1962) Ecology of Scolytidae. *Annual Review of Entomology* **7**, 327–348.

Schmitzet, G. & Crisinel, P. (1957) *La lutte contre* Stephanoderis hampei *Ferr***.** 156 pp. Publicaciones of the Institut Nacional pour L'Etude Agronomique du Congo Belge (INEAC). Serie Scientifique **70**.

Schmutterer, H. (1990) Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. *Annual Review of Entomology* **35**, 271–197.

Solís-Morán, H. (1986) Medidas de control de la broca del cafeto *Hypothenemus hampei* oficialmente recomendadas en El Salvador. *Memorias del II Taller Internacional sobre la Broca del Grano del Café (*Hypothenemus hampei*, Ferr.). IICA, Tapachula, Mexico*. pp. 73–74.

Sponagel, K.W. (1994) *La broca del café* Hypothenemus hampei *en plantaciones de café robusta en la Amazonía Ecuatoriana*. 191 pp. Giessen, Germany, Wissenschaftlicher, Fachverlag.

Ticheler, J. (1961) Etude analytique de l'épidémiologie du scolyte des graines de café *Stephanoderis hampei* Ferr. en Cote d'Ivoire. *Mededelingen Landbouwhogeschool Wageningen* **61**, 1–49.

Toledo-Piza-Junior, S. (1928) *Heterospilus coffeicola* Schmied. Parasita da 'broca do café' *Stephanoderis hampei* (Ferr.) *Archives of the Institute of Biology* **6**, 179–199.

Urbina, N. (1987) La broca del fruto del cafeto, *Hypothenemus hampei*, y su control. Proyecto de Manejo de Plagas. CATIE, Panama. pp. 48–59.

Valencia, J.A., Ruiz, S.L., Gonzalez, G.M.T., Riaño, H.N.M. & Posada, F.F.J. (1994) Efecto de inhibidores de proteinases sobre la actividad trypsina y quimotrypsina de *Hypothenemus hampei* (Ferrari). *Cenicafé* **45**, 51–59.

Vega, R., Gonzalez, M.O. & Rauda, A.M. (1991) Investigaciones referentes al control biológico de la broca del cafeto, *Hypothenemus hampei*, mediante parasitoides de origen africano. *14th Simposio sobre la Cafeticultura Latinoamericana. Panama*. pp. 231–254.

Waterhouse, D.F. & Norris, K.R. (1989) *Biological control: Pacific prospects. Supplement 1.* Australian Centre for International Agricultural Research, Canberra. pp. 56–75.

(Accepted 1 August 2000)