Augmentation of *Mirax insularis* Muesebeck. Alternative for population control of the coffee leaf miner, *Leucoptera coffeella* Guérin-Ménéville, in Puerto Rico[1]

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ABSTRACT

A biological control program for the suppression of the coffee leaf miner (CLM), *Leucoptera coffeella* Guérin-Méneville, populations in Puerto Rico is promising. Such a project is favored because of stable habitat, host specificity of the pest, indirect pest and salubrious environment. Because of the negative ecological impact of chemical applications for controlling CLM populations, it is important to select an alternative to supress this pest in the shortest time possible. Classical biological control, new associations and other techniques such as augmentation are feasible approaches. Augmentation seems the most appropriate because it requires no time-consuming foreign exploration and quarantine procedures. *Mirax insularis* Muesebeck can be augmented in the field just before CLM population peaks by mass liberations of parasitoids reared in greenhouses. This approach is possible because the braconid is well adapted to Puerto Rican coffee plantations and the biology and phenology of the host is well known. To properly evaluate the impact of a biological control program, it is necessary to establish an economic threshold of the CLM damage.

RESUMEN

Una alternativa para limitar la población del minador del café: la aumentación de *Mirax insularis*

Un programa de control biológico del minador de la hoja del cafeto, *Leucoptera coffeella* Guérin-Méneville, en Puerto Rico parece ser prometedor. Dicho programa es factible porque las plantaciones de café proveen un ambiente estable, el minador es una plaga específica del café y que le ocasiona un daño indirecto. Debido al impacto ecológico ocasionado por las aplicaciones de insecticidas granulares para controlar el minador es necesario seleccionar la mejor técnica de control biológico, una que disminuya la población de la plaga en el menor tiempo posible para evitar la contaminación química. Varias técnicas de control biológico (control biológico clásico, nuevas asociaciones, incrementación) se evaluán desde el punto de vista teórico; todas parecen ser prometedoras. Sin embargo, la incrementación parece ser la más apropiada debido a su sencillez en comparación con otras técnicas que requieren complicados procedimientos tales como: exploración en el extranjero, cuarentena, etc. La incrementación de la población del parásito, *Mirax insularis* Muesebeck (Hymenoptera: Braconidae), en el campo, justo antes de que las poblaciones del minador

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aumenten, se puede realizar utilizando liberaciones masivas del parásito criado en invernaderos. Esta técnica es posible ya que el bracónido está bien adaptado en toda la región cafetalera de Puerto Rico. Además, se sabe la biología y fenología del minador del café y éste se puede criar usando técnicas de laboratorio. Es necesario, sin embargo, determinar el umbral económico del daño del minador de tal manera que se pueda evaluar apropiadamente el impacto de un programa de control biológico.

INTRODUCTION

Coffee, *Coffea arabica* (L.), is the main agricultural crop of Puerto Rico. One of the limiting factors in coffee production is the coffee leaf miner (CLM), *Leucoptera coffeella* Guérin-Méneville. The caterpillar of this silvery moth penetrates the leaf and feeds on the mesophyll for about 3 weeks, thus producing irregular brown spots. The CLM damage reduces up to 50% of the photosynthetic activity of the leaves, causes defoliation and reduces yield by up to 40% (7). In Brazil, 21.6% loss was reported in coffee yields when 46.24% of the leaves were damaged by the CLM (40).

Each year the coffee industry of Puerto Rico spends around $1 million in chemical control of the CLM (14). This control is achieved by annual applications of the granular systemic insecticide, disulfoton 15 G (42). Heavy rains during application season cause granules of the systemic insecticide disulfoton 15G to contaminate streams (18). Because of the contamination and possible development of resistance by CLM to disulfoton 15 G, other control tactics with less damage to the environment, such as biological control, should be evaluated and considered.

Ecological Impact of the CLM chemical control in Puerto Rico

Intensive modern techniques are used to grow unshaded coffee in the West-Central region of the island at elevations that range from 500 to 3000 ft. above sea level. That region comprises 432,081 acres, 19% (81,715 acres) of which are dedicated to coffee (43). Fifty percent of the coffee plantations are grown at 60% slope or more. Rain is abundant in that area; 95 inches is the annual average (42). Under these conditions, the application of granular insecticides is difficult and runoff likely after heavy showers. Down stream and through contamination of other agricultural products a large population is potentially exposed to insecticide contamination. Therefore, non-contaminating control measures, such as biological control, are preferred.

The introduction of natural enemies can be achieved by using old or new associations. The former comprises long-evolved associations between parasite-host or predator-prey (28). New associations involve the use of new parasite-host or predator-prey associations not based on long-evolved associations as in old associations (28). Other biocontrol techniques include periodic release, augmentation, inundative release, and manipulation of natural enemies (9).

The biocontrol of the CLM populations in Puerto Rico can be approached by using new and old associations and other such techniques. Biogeography of pest and host plant, pest evaluation, and natural enemy lists are the first subjects to be evaluated before starting such a project (53). This paper presents a review of these subjects and the possibilities of a biocontrol project as an alternative for the population control of the CLM in Puerto Rico.

BIOGEOGRAPHY OF THE PEST AND HOST

Coffee origin and distribution

Ten coffee species coexist in tropical Africa and one *Mascarocoffea* in Madagascar (8). Three of them are of economic importance: *C. arabica*, *C. canephora* (Robusta coffee) nd *C. liberica* (Liberian coffee). *C. arabica* has figured most prominently in history and now accounts for more than 90% of the world's coffee production. Robusta and Liberian coffees produce about 9 and 1%, respectively (5).

Coffee, *C. arabica*, is indigenous to Ethiopia, where it grows wild in a small part of the Ethiopian hills extending into Sudan (49). About AD 850, coffee was cultivated in the Arabian colony of Harar from where it spread to Mecca from whence it was taken home by pilgrims to other parts of the Islamic world (8).

Coffee plants from Yemen were introduced in Java in 1690 and 1699 by the Dutch (44). A plant from Java was taken to Amsterdam Botanic Gardens in 1706 and from there to France in 1713. Planting material was sent from Amsterdam to Surinam in 1718, from where the French obtained it for Cayenne in 1722 and from there it was taken to Brazil in 1727 (44).

Progeny from the French material was sent by Louis XIV from Paris to its Caribbean colony of Martinique about 1723. Only one plant survived the journey (5). From that plant, progeny was developed and spread to other Caribbean islands, Central and South America.

The coffee plant involved in all early introductions was of the variety *typica* (*C. arabica* L. var. *arabica*) (44). Thus the variety that predominates in the New World tropics is *typica*. Another economic important variety is *Bourbon* (*C. arabica* L. var. *bourbon*). This variety occurs in Ethiopia and was introduced by the French to Bourbon (Reunion) about 1718 (44). Progeny from Reunion coffee was taken to the New World.

Zoogeographical distribution of the CLM

Coffee originated in Africa so it is to be expected that this continent has the greatest range of pests. There are over 900 insect species that attack the coffee plant the world over. Of the insect pests, roughly 400 are Ethiopian, 250 are Oriental and 200 Neotropical (36). Twenty-one percent are Lepidoptera; the *Leucoptera* spp. complex are the most important group.

The CLM-complex include *L. meyricki*, *L. coma*, *L. caffeina*, and *L. coffeella*. The first three are found exclusively in Africa. *L. coffeella* is confined to South and Central America, and the West Indies. *L. meyricki* is the most common of the African species being reported from the Ivory Coast, Angola, Congo, East Africa, Ethiopia and Madagascar (27).

L. coffeella was discovered and described in 1842 by Guérin-Méneville and Perrottet on coffee from the Caribbean islands of Guadeloupe and Martinique (24).

Taxonomy status of the CLM

Guérin-Méneville and Perrottet (24) placed the CLM in the genus *Elachista*. Later it was referred to by Station as *Cemiostoma* (48). Through a misidentification, the common *L. meyricki* found in Africa was referred to as *coffeella* in nearly all the literature up to 1958, when Bradley (4) eliminated the confusion by distinguishing it from *L. coffeella*. The Brazilian Silvestri (47) proposed the generic name *Perileucoptera* for *L. coffeella*. This genus is used only in Brazil (12).

PEST EVALUATION

Pest Status

L. coffeella is a major pest of coffee in all countries of the New World. Cultivated varieties of *C. arabica* are attacked by the CLM, although some differences of preference among the varieties have been observed (17, 21).

Until 1850, plantations in Brazil were free of the pest, but at the time plants were introduced from the Antilles, and the year after, leaves were attacked (39). In Puerto Rico, the first record of CLM was reported in 1903 (1). Since then, the CLM has been studied by different entomologists (16, 17, 18, 19, 20, 21, 29, 42, 45, 46, 51, 55).

Life history and phenology of the CLM in Puerto Rico

The life cycle of the CLM in Puerto Rico was described by Hooker (29) and van Zwaluwenberg (50, 51). It takes about 13 to 38 days, depending on climatic conditions. All life stages occur throughout all the year, with two population peaks that coincide with the dry seasons (May-July and December-February) in the coffee region (16). Shorter generations occur during the summer season (May-July), because of high temperatures, and longer generations during the winter season (December through February), at lower temperatures. There are as many as 14 generations of the CLM per year (16).

NATURAL ENEMIES LIST

America

The first to mention parasites to CLM in America was B. P. Mann (39), who studied the bionomics of this pest in Brazil. He described two parasitoids, one feeding upon larva, *Eulophus cemiostomatis*, Mann, the second hatching from the pupa, named *Bracon letifer* Mann. Later, Giard (22) and Box (2) refer to *B. letifer* as *Exothecus letifer* Mann. Neither of the two parasitoids has been observed again.

Hooker (29) and van Zwaluwenburg (52) recorded two other parasitoids of the CLM in Puerto Rico, both Chalcids, *Chrysocharis livida* Ashmead and *Zagrammosoma multilineatum* Ashmead. These two species are also recorded from Puerto Rico by Wolcott (55) and were found in Venezuela by Box (3). In Brazil, van Inhering (52) described three new Chalcid parasitoids of the CLM, which he named *Closterocerus coffeellae*, *Eulophus* sp. and *Procarias coffeae*.

In Cuba, Bruner (6) discovered four other Chalcids parasitizing the CLM, the most common *Horismenus cupreus* Ashmead, *Closterocerus cinctipennis* Ashmead, and *Zagrammosoma multilineatum* Ashmead. Sein (45) reported the Braconid *Mirax insularis* Muesebeck, parasitizing 65 to 80% of the CLM larvae in Guadeloupe.

Wolcott (55) reported 10 species reared from the CLM larvae in Puerto Rico. These are arranged in order of abundance: *Closterocerus lividus* Ash., *Horismenus cupreus* Ashm., *Zagrammosoma* sp. nov., *Closterocerus* sp. near *cinctipennis* Ash., *Cirrispiloideus* sp. nov, *Derastenus* sp. near *fullawayi* Crawford, *Tetrastichus* sp. nov., *Telenomus* sp. and *Microbracon* sp. Gallardo-Covas (20), in a survey done in 1985-86 throughout the coffee region of Puerto Rico, found only five eulophids: *Achrysocharoides* sp., *Chrysonotomyia* sp., *Cirrospiloideus* sp., *Zagrammosoma* sp., *Horismenus* sp., and a braconid, *Mirax insularis*, attacking larvae of the CLM.

Thus, from the literature, 18 species of parasitic Hymenoptera are known to live on the CLM in America, either as primary or as secondary parasites: Braconidae: *Mirax insularis* Muesebeck, and *Microbracon* sp.; Eulophidae: *Acrysocharoides* sp., *Chrysocharis lividus* Ashm., *Chrysonotomyia* sp., *Cirrispiloideus* sp. nov., *Closterocerus leucopus* Ashmead, *Closterocerus coffeellae* Inhering, *Closterocerus* sp. near *cinctipennis* Ashmead, *Derastenus fullawayi* Crawford, *Eulophus* sp., *Horismenus* sp., *Horismenus cupreus* Ashmead, *Procarias coffeae* Inhering, *Telomomus* sp., *Tetrastichus* sp. nov., *Zagrammosoma* sp. nov. *Zagrammosoma multilineatum* Ashmead.

Africa

Larvae and pupae of the coffee leaf miners *L. meyricki* Chesq. and *L. caffeina* Washb., in Africa are attacked by hymenopteran parasites in the families Eulophidae, Pteromalidae, Elasmidae, and Braconidae (11, 15, 31, 35, 54). There are 19 species either as primary or as secondary parasites: Braconidae: *Apanteles bordagie* Giard and *Mirax leucopterae* Wilk.; Pteromalidae: *Trigonogastra nigricola* Ferr.; Elasmidae: *Elasmus leucopterae* Ferr.; Eulophidae: *Achrysocharella ritchiei* Ferr., *Chrysocharis lepelleyi* Ferr., *Chrysocharis lamellata* Kerrich, *Cirrospilus crowei* Kerrich, *Cirrospilus longifasciatus* Ferr., *Cirrospilus cinctipennis* Ferr., *Closterocerus africanus* Wat., *Derostenus coffeae* Ferr., *Eulophus borboricus* Giard, *Pediobius coffeicola* Ferr., *Sympiesis bukobensis* Ferr., *Sympiesis comosus* Kerrich, *Teleopterus violaceus* Ferr., *Tetrastichoides leucopterae* Ferr. and *Zagrammosoma variegatum* Masi.

Most of these parasitoids have been recorded from Kenya, Tanzania and Uganda.

ATTEMPTS AT BIOCONTROL

Despite the large numbers of parasitoids of the CLM complex around the world, little effort has been made to utilize them as biocontrol agents. This condition is attributed to the complications occasioned by many of the eulophids that are primary parasites, if the host larva has not been previously attacked, and secondary or even tertiary if it has (36). In Africa, the use of foliar insecticides to control *L. meyricki* and hyperparasitism were the factors that contributed to the breakdown of the biocontrol of the leaf miner (10).

The braconid, *Mirax insularis*, destroys from 65 to 85% of the CLM larvae in Guadeloupe (45). Sein (45, 46) introduced *M. insularis* to Puerto Rico from Guadeloupe in 1937. Recovery tests indicated that it became permanently established although the incidence was very low. The parasitoid was released in shaded coffee groves at Lares and Quebradillas. In 1938, it was recovered at Lares and Quebradillas up to November. Seín attributed that paucity to the seasonal scarcity of its host. After that, no more recoveries were made until May 1986, when seven specimens were collected at Lares (20). Gallardo-Covas (20) demonstrated that it is permanently established throughout the coffee region of Puerto Rico. *M. insularis* constituted 32.4% of the total parasitoid population in 1985-86 in Puerto Rico (20). In Puerto Rico, the action of the parasitoid complex upon CLM populations caused 15 to 25% parasitism (20, 45).

M. insularis has been transferred several times between different Caribbean islands. An attempt to introduce it to Kenya from Dominica was made in 1962, but the parasitoid did not attack the East African species of *Leucoptera*. Attempts have been made in the opposite direction; that is, East African parasites have been introduced to the West Indies (23). These, too, were abortive. No other attempts have been conducted in the New World to control the CLM populations using natural enemies.

DISCUSSION

Possibilities at Biocontrol

There is no doubt that biocontrol holds great promise for the control of many coffee insects (36). The conditions that prevail in the Puerto Rican coffee plantations favor the probabilities of success of a biological control program against the CLM.

First, the coffee plant is a perennial tree (stable habitat), growing in conditions that allow a constant succession of the CLM generations. It is in that habitat that most biological control success has occurred (26, 37). Second, the CLM is an indirect and specific pest of coffee. Indirect pests are more appropriate targets for biological control (9). Third, Puerto Rico is a tropical island with a mild warm climate (salubrious environment). It is under island conditions that a high degree of success is expected because of the low biota and with many ecological niches available (23, 38). Islands have a higher rate of establishment than continents (26). The next step is to evaluate the approaches to be followed such as classical biocontrol, new associations and other techniques (augmentation or periodic releases).

Classical Biological Control of the CLM

The first consideration in establishing a classical biocontrol program is to determine the exact origin of the pest and its host. A foreign origin of the CLM is suspected because there are no native species of its hosts in the New World and it is not known to attack any native plants. Therefore, it is clearly established that the CLM is not native to the Americas.

Determination of the exact point of origin of the CLM is difficult because it has not been recorded on any commercial coffee plantation in Africa. Also, no studies have been made to determine its presence in wild coffees or Rubiaceae plants. In Africa, all the efforts have been toward the suppression of its relative *L. meyricki*. It is suspected that the Ethiopian region is the place of origin of the CLM. The fact that the first New World record of the CLM was in Martinique in 1842 (24) on progeny of coffee plants of Ethiopian origin suggests that area as the first place to explore for parasitoids. Emphasis should be given to search on wild coffee species and other Rubiaceae.

The establishment of a classical biological control program seems to be a feasible approach for controlling CLM populations in Puerto Rico. Major concerns to this approach are costs and the prospects of a long term project. Moreover, some natural enemies are refractory to culture and study and this may involve long periods of research. Furthermore, where there is little or no guidance to be had from earlier investigations the costs will be higher.

New Associations

The new associations approach is based on the ecological principle of avoiding the tendency of parasites and hosts to evolve some degree of balance (28). This approach consists in using new parasitoid-host associations.

Two such attempts, both abortive, were made in 1962 when *M. insularis* was introduced to Kenya from Dominica and *Apanteles bordagei* was introduced to Dominica from Kenya. The parasitoids failed against their new hosts (23).

To further new associations between African parasitoids and the American *Leucoptera*, a detailed study of the interspecific competitions of the existing parasitoids in America, followed by a similar work in Africa, might result in finding parasitoids of satisfactory potential for trial. The parasitoid selected should be a good competitor against the natural enemy fauna of the CLM on both continents. There are 19 species of Hymenoptera parasitic on the larvae and pupa of *Leucoptera* spp. in Africa, and 15 in America. In Africa, the complexity is considerable because many of the eulophids are primary parasites, if the host larva has not been previously attacked, and secondary or even tertiary if it has (36). The situation in Puerto Rico among the interspecific competition of the CLM parasitoids is not known. It should be relatively simpler because total parasitoid fauna is lower than in Africa. The system is composed of one braconid and four eulophids.

Testing to ascertain that the parasitoids of the African CLM breed in *L. coffeella* is the first step to be taken in such a project. Precautions should be taken to prevent the introduction of hyperparasitic species. The same steps needed for conducting a classical biocontrol program should be followed here. There is a high potential for this approach with so many promising African species.

Augmentation

Several methods for increasing entomophagous insects have been tested (13, 25, 34, 41). One such method includes the increase of the population of the parasitoid directly through insectary propagation and release into the environment (32).

Augmentation using *M. insularis* seems to be the most promising for conducting a biocontrol program of the CLM in Puerto Rico. The imported parasitoid *M. insularis* is well distributed in all the ecological areas of the coffee region of Puerto Rico. It constituted 32.4% of the total parasitoid population and exerted 14.8% parasitism (20). Although a parasitoid may parasitize only 5-10% of its hosts, it will not necessarily be a poor candidate for augmentation. On the contrary, such a parasite may dramatically reduce a pest population if the natural parasite population can be increased 10 to 25 fold at strategic times (32). The fact that the parasitoid is established eliminates all the costly and time consuming steps needed to follow when the classical or new associations are tried.

King et al. (32) stated that promising candidates for augmentation should possess some of the following characteristics: adaptation to the abiotic environment, appropriate host range, high searching ability on target host, synchrony with host life cycle, high capacity for increase, pesticide tolerance and ease for economical mass-rearing. *M. insularis* has some of these characteristics (19), but it is necessary to evaluate whether high populations can be economically attained in laboratory cultures.

The rearing method for the CLM developed by Katiyar and Ferrer (30) seems the solution to mass-rearing of the host. They indicated that the cost of rearing a sufficient number of moths would not be excessive. The same rearing technique can be used to start the mass-rearing of *M. insularis* under greenhouse conditions so that further liberations of parasitoid adults can be made in the field.

This parasitoid can be mass-reared under greenhouse conditions and released just before the CLM population peaks. As stated previously in this paper, the CLM presents two population peaks each year, with the May-July peak higher than the December-February peak. Field liberations of the braconid can be made just before these peaks. Greenhouse mass rearing of the parasitoid can be started in August and continued through mid December, when periodic liberations begin and continue up to the end of February. Liberations of adult parasitoids can be restarted again at the end of April and continued through July.

Several studies are needed in order to establish an augmentation program for the braconid *M. insularis*. These include the establishment of an economic threshold for the CLM damage; study in detail of the biology of *M. insularis* in order to improve the mass rearing technique and determination intra- and interspecific competition of the CLM parasitoids in Puerto Rico.

Augmentation seems to be the most feasible and inexpensive way to start a biocontrol project of the CLM in Puerto Rico. This system does not need foreign explorations and quarantine procedures. The urgency for a biocontrol program of the CLM in Puerto Rico is the key factor that determines the use of the fastest approach available. Augmentation of one of the promising parasitoids of the CLM seems to be that approach.

CONCLUSIONS

The implementation of a biological control program for the suppression of the CLM populations in Puerto Rico is promising. Such a project has probabilities of success because of stable habitat, host specificity of the pest, indirect pest and salubrious environment. Because of the negative ecological impact of chemical applications for controlling the CLM populations, it is important to select other types of non-contaminating control. An approach that may suppress this pest in the shortest time possible would be the best. Time is an important factor in selecting one of the biological approaches.

Classical biological control, new associations and other techniques, such as augmentation, all seem to be feasible approaches. Augmentation is the most appropriate because it requires no foreign exploration and quarantine procedures. Augmentation should be the most rapid of the three approaches to give some results.

Augmentation of *Mirax insularis* in the field just before the CLM population peaks can be achieved by mass liberations of parasitoids reared in greenhouses. That approach is possible because the braconid is well adapted to the Puerto Rican coffee plantations, and the biology and phenology of the host is well known.

It is necessary to establish an economic threshold in coffee for the CLM damage to properly evaluate the impact of a biological control program. Augmentation is the most feasible, fastest and least costly of the three approaches.

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