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Bibliographic review

Cocoa pest management in organic and agroecological systems

Manejo de plagas del cacao en sistemas orgánicos y agroecológicos

Erick Trigozo-Bartra[1], Adan Ricardo Pasapera Vásquez[1], Augusto Rucoba-Chujutalli[1], Martín Sánchez-Ojanasta[1], Murilo Fuentes Pelloso[2], Cassia Siqueira Bahia[3], Fernando Teruhiko Hata[4*]

[1]Universidad Nacional de San Martín - Perú; Jr. Maynas N° 177, Tarapoto, San Martín, Perú.

[2]Universidade Estadual de Mato Grosso do Sul - Brasil Rodovia BR-163 km 235, Mundo Novo, Mato Grosso do Sul, Brasil.

[3]Instituto Biofábrica da Bahia - Brasil; Rodovia BA-262 km 32, Ilhéus, Bahia, Brasil.

[4]Universidade Estadual de Maringá - Mestrado Profissional em Agroecologia; Av. Colombo, 5790, Maringá, Paraná, Brasil.

ABSTRACT: *Theobroma cacao* cultivation is affected by insect pests that cause damage and significantly reduce both quality and yield. The aim of this article was to compile bibliographic material on the most commonly used agroecological control methods in cacao cultivation. The main cacao pests reviewed in this article are the cacao pod borer (*Carmenta* spp.), the mirid bug (*Monalonion* spp.), leaf-cutting ants (*Atta* spp.), white grubs (*Phyllophaga* sp.), and the coffee berry borer (*Xyleborus ferrugineus*). For the agroecological control of cacao pests, the use of beneficial organisms is recommended, mainly fungi such as *Metarhizium* sp. and *Beauveria bassiana*, as well as bacteria such as *Bacillus thuringiensis*. In addition, conservative biological control may be an option to enhance and preserve the natural enemies present in the agroecosystem. These strategies are a crucial part of efforts to reduce the use of agrochemicals in agricultural crops because, beyond their negligible impact on environmental pollution, their application has been justified by enabling the development of sustainable agriculture that contributes to the conservation of natural resources.

Key words: Biological control, *Theobroma cacao* L., entomopathogen, predators.

RESUMEN: El cultivo de *Theobroma cacao* es afectado por insectos plagas que ocasionan daños y reducen significativamente la calidad y el rendimiento. El objetivo del artículo fue la recopilación de material bibliográfico sobre los tipos de control Agroecológico más empleados en el cultivo. Las principales plagas del cacao que revisaremos en este artículo son: mazorquero de cacao (*Carmenta* spp.), chinche mosquilla (*Monalonion* spp.), hormigas curuhuinsi (*Atta* spp.), gallina ciega (*Phyllophaga* sp.) y barrenador (*Xyleborus ferrugineus*). Se recomienda para el control agroecológico de plagas del cultivo de cacao, el uso de organismos benéficos, principalmente hongos, como *Metarhizium* sp. y *Beauveria bassiana* y bacterias como *Bacillus thuringiensis*. Además, el control biológico conservativo puede ser una opción para aumentar y conservar los enemigos naturales presentes en el agroecosistema. Son parte crucial del esfuerzo por reducir el uso de agroquímicos en los cultivos agrícolas porque, además de su nulo impacto en la contaminación ambiental, su uso se ha justificado por permitir el desarrollo de una agricultura sostenible que permite conservar los recursos naturales.

Palabras clave: Control biológico, *Theobroma cacao* L., entomopatógeno, depredadores.

[*]Author for correspondence: hata.ft@hotmail.com

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INTRODUCTION

Cocoa, *Theobroma cacao* L., is a valuable agricultural product of global economic importance. Cocoa-derived products, such as chocolate and beverages, are significant for various countries, in addition to offering health benefits, as they are rich in bioactive compounds, especially polyphenols (1,2).

The growth and yield of a cocoa crop critically depend on integrated pest management (IPM) and pollinators (3). Due to the high prevalence of pests, as well as the presence of diseases, excessive shade, nutritional deficiencies, inadequate pruning, and cloning with inferior genetic material, a cocoa plantation can suffer a drastic reduction in productivity (4). The goal of integrated pest management is to prevent economic damage to cocoa farmers. It employs a series of procedures that allow creating unsuitable environments for the growth and spread of pathogens, thereby drastically reducing their presence in plants and cropping environments (5). In agroecological management, products of synthetic origin are prohibited, and there are specific standards for pest control, defined by current legislation for organic production. Therefore, methods such as biological, cultural, and genetic control are prioritized in organic and agroecological systems.

This comprehensive review describes control methods as part of integrated management in organic and agroecological systems, with an emphasis on the main cocoa pests.

METHODOLOGY

A systematic review of the scientific literature was conducted based on an adaptation of the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The research question established to guide the methodological process was the following: What biological control methods are applied in agroecological agricultural systems for the integrated management of cocoa cultivation? Furthermore, the review encompasses descriptive and experimental studies on this topic. For the information collection, only original articles published in scientific databases (Google Scholar, Scopus, Web of Science, PubMed) with full-text digital access were included, considering articles in English, Spanish, and Portuguese within the time frame of 2014 to 2024, addressing cocoa pest management in organic and agroecological systems, excluding opinion articles or scientific communications.

Additionally, to ensure the sensitivity of the search process, the following terms were defined as descriptors based on the research question: "biological control," "cocoa," "pests." However, to refine the systematic review search, Boolean operators were used, such as: ("cocoa biological control" and "agroecology"), ("integrated pest management" and "cocoa"), ("cocoa pod borer" and "mosquito bug"), ("curuhuinsi ants and cocoa") and ("white grub") and ("borer").

Integrated pest management in Cocoa cultivation

Since cocoa is a valuable agricultural crop that can be both exported and consumed domestically, effective control of insect pests is necessary to increase production (6). Cocoa production is hindered by a high diversity of insect pests, resulting in a substantial reduction in tree growth and yield (4).

Conventionally advised cultural management methods include the periodic disposal of contaminated products. However, as these methods are time-consuming to implement, which costs money, small-scale producers (who often have modest incomes) find them unattractive. As a result, in addition to management plans, producers should be provided with methodological tools that enable them to develop their own management plans based on their circumstances and available resources. Therefore, it is crucial to develop, implement, evaluate, and report integrated pest management protocols that lead to a notable and substantial decrease in crop losses as a result of these diseases and, consequently, to increased farmers' profits, yields, and income (7).

To increase tree health, these protocols should incorporate cultural practices (such as weekly removal of diseased fruits) accompanied by other direct disease management techniques (such as the use of pesticides permitted in organic agriculture) and microclimate control, among other methods, to decrease the prevalence and severity of infections (8).

It is also vital that IPM procedures cover elements beyond the direct influence of the pathogen, allowing farmers to make decisions supported by scientific evidence regarding the use of control measures by being aware of any imbalances in their cropping system. The four factors that should be considered and focused on as action points or control points in any management plan designed to decrease the impacts of a disease are: producer actions, pathogen, host, and environment. IPM tactics take into account and focus on these four elements, as the effectiveness of a strategy increases with the number of elements it targets (8).

One of the most widely used control methods is biological control. The definition of biological control is described as an ever-expanding agricultural technique that aims to eradicate or destroy pathogens and insect pests, often using their natural enemies (9,10). In addition to insects, mites, and microorganisms, bats and birds are important generalist predators in cocoa systems, which aid in the natural control of insect pests, reduce plant damage, and contribute to increased cocoa productivity (11,12).

There are various organisms that carry out pest control; however, few of them are produced on a large scale so that farmers can acquire them and release them in the field. Therefore, it is important to implement management tactics that favor, in the cropping environment, the development of these biocontrol agents. In this context, conservative biological control is essential for predators, parasitoids, and microorganisms to find suitable conditions for their development.

Main pests and agroecological management methods

The main cocoa pests in Latin America, which we will review in this article, are the following: cocoa pod borer (*Carmenta foraseminis* Eichlin), mosquito bug (*Monalonium dissimulatum*), curuhuinsi ants (*Atta cephalotes*), white grub (*Phyllophaga* sp.), and borer (*Xyleborus ferrugineus*).

Cocoa pod borer: *Carmenta spp*

In recent years, the insects *Carmenta foraseminis* Eichlin (Lepidoptera, Sesiidae) (Figure 1A) and *Carmenta theobromae* Busck (Lepidoptera, Sesiidae), species reported in Latin America as the "cocoa pod borer," "fruit borer," "cocoa fruit borer," or "broca do fruto do cacaueiro" (Brazil), have infested plantations, putting the production and quality of cocoa beans at risk (13). Consequently, these insects negatively impact its development, reducing the length and weight of the fruit, as well as the weight of the beans, both in wet and dry conditions (Figures 1B and 1C).

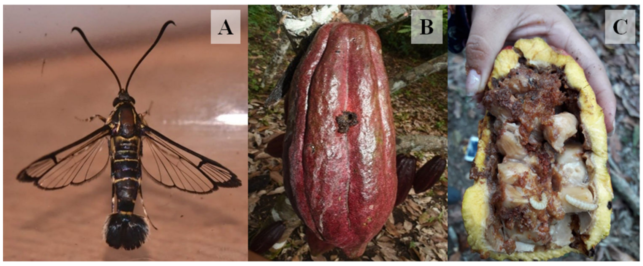

Figure 1. A) Adult of *Carmenta foraseminis*; B) Fruit perforated by *C. foraseminis* larva; C) Fruit completely damaged by larval feeding.

Bean loss per fruit due to direct damage ranges from 5 to 13 %, while 70 to 90 % is lost as a result of indirect damage caused by the entry of rainwater, fungi, bacteria, and other insects through the exit holes left by *C. foraseminis* adults (13). It is estimated that its infestation can cause up to 40.4 % damage to seeds, of which approximately 9.5 % are completely lost, becoming unviable for any type of commercial use (14).

The life cycle of the cocoa pod borer, at a temperature of 28 °C and 80 % relative humidity, comprises an incubation period of 7-8 days; the larval phase (up to the fifth instar) lasts between 30 and 36 days; the pupal stage, between 21 and 22 days; and the adult phase, 6-7 days. Together, the life cycle ranges from 64 to 73 days, with an average of 68.5 days (13). Newly oviposited eggs are reddish-brown in color and oval-elongated in shape (2.4-3.2 × 1.7-2.2 mm), with fine longitudinal striations on their surface, with oviposition typically occurring on pods 80 to 120 days old, and fruit infestation beginning at 2.5 months of age. Results found by some authors suggest that the pest benefits from warmer and drier conditions (15,16).

Continuous monitoring is essential to estimate pest population abundance and distribution, allowing the adoption of more effective control strategies (17). For integrated management of *C. foraseminis*, three important cultural practices are recommended: pruning of cocoa trees, timely harvesting every 14 days or during peak harvest periods every 10 to 12 days, and treatment of cocoa husks by covering them with plastic or applying antispore-forming substances (lime, 20 % salt water, or 15 % urea solution) (13).

As a biological control measure, *Beauveria bassiana* can be used on *C. foraseminis* eggs (18). Regarding insects, *Telenomus* sp. (Hymenoptera: Scelionidae), *Trichogramma* sp. (Hymenoptera: Trichogrammatidae) have been reported preying on eggs; *Brachymeria* sp. (Hymenoptera: Chalcididae), *Pimpla sanguinipes*, *Scolomus* sp. (Hymenoptera: Ichneumonidae), *Bassus brullei*, *Bracon* sp., *Parapanteles* sp., and *Apanteles* sp. (Hymenoptera: Braconidae) parasitize larvae-pupae; and *Calliephialtes* sp. (Hymenoptera: Ichneumonidae), *Brachymeria pedalis*, and *B. conica* (Hymenoptera: Chalcididae) parasitize pupae (19,20).

Cocoa Bug: *Monalonion spp*

The cocoa bug, belonging to the order Hemiptera, family Miridae, known as cocoa bug, grajo, chupador, or monalonion, is recognized as a pest of great importance, causing losses of 15 to 80 % in Peruvian plantations (21), the main country where this pest insect occurs (22).

Nymphs feed directly on shoots, stems, and fruits of the cocoa tree, sucking the sap. This activity compromises plant development, product quality, and acts as a key factor in the spread of diseases such as moniliasis and brown pod rot, among others (23-25). Additionally, adults suck sap from the endocarp, causing lesions that result in malformations, reduction in fruit size, and in more severe cases, abortion of young fruits (26).

Three types of this family are known to be pests, including species of *Monalonion* that affect cocoa cultivation, namely *Monalonion dissimulatum* Dist., which affects immature and mature fruits. *Monalonion annulipes* attacks shoot tips of branches and generally tender tissues; the species Monalonion itabunensis is also known. The damage originates from the toxic saliva of the bugs, which with their sucking mouthparts destroy new shoots and tender fruits (6). The insect threshold of >0.7 bugs tree^{-1} is the threshold for taking control measures (27). The duration of the cocoa bug's biological cycle is 48 to 60 days, and the adult stage has a lifespan of 25 to 30 days (28).

Research in Colombia demonstrated that *M. dissimulatum* is highly susceptible to the effect of applications of the entomopathogenic fungus *Beauveria bassiana* at any stage of its development. Mortality begins between 4 and 6 days after application. Recommended doses range from 2.5 × 10^8 to 7.5 × 10^8 conidia per milliliter of suspension (29).

Recently, a new species of Uscanoidea Girault parasitizing *M. dissimulatum* eggs was reported in Colombia, presenting high potential for biological control of the pest in cocoa plantations (30). Furthermore, the use of bioinsecticides containing wild garlic, dehydrated tobacco, and neem can favor the control of nymphs and adults of bugs that cause damage to cocoa fruits (31). Predatory insects such as *Zelus pedestris*, from the Reduviidae family, can control *M. bondari* at all stages of its development (32).

Currently, the use of Agroforestry Systems (AFS) in cocoa cultivation has increased, integrating forest species and other vegetative components that generate shade. However, when this shade is not adequately managed, it can create favorable microclimatic conditions for the development and incidence of pests such as the cocoa bug (6). High temperatures combined with excessive shade contribute to an ideal habitat for these insects, affecting crop health (33). Therefore, more than the AFS itself, the problem lies in the lack of implementation of adequate shade regulation and control practices. Avoiding excessive shade in the plantation constitutes a fundamental practice within cocoa cultural management. In this sense, it is essential to carry out timely maintenance pruning on both cocoa plants and shade trees, in order to ensure adequate ventilation and lighting within the productive system (34). These practices favor the reduction of microclimatic conditions conducive to the development and proliferation of pests, evidencing the importance of pruning as a key agronomic strategy in integrated crop management (35). Likewise, shade regulation contributes to bug control by limiting favorable environments for its establishment and reducing the impact of its populations in cocoa plantations.

On the other hand, cultural practices are not carried out during the period of greatest sprouting of new leaves and appearance of tender fruits, with shade thinning and branch removal from the plantation to provide more light for better bug control (36).

Curuhuinsi Ants: *Atta* spp

As occasional causes of damage to cocoa, several ant species act by cutting leaves to take them to their deposits as substrate, as on the deposited leaves of cocoa and other plants, they cultivate fungi that are actually their food. Among the ant species that cause damage to cocoa are the leafcutter ant whose scientific name is *Atta cephalotes* and other species of the same genus *Atta* that cut leaves and carry them along paths to the anthill built by them underground, composed of innumerable cavities or galleries in which they live and cultivate the food fungus (37).

The most effective method consists of eliminating the queen, which is responsible for the reproduction of the entire anthill, destroying its direct source of food, the fungus it cultivates. The cultivation of repellent plants, such as *Canavalia*, enhances ant control by promoting biodiversity, thus constituting one of the most effective tools for their management since these become pests in natural forest areas that are replaced by agricultural activities (37). Bioinsecticides developed from filamentous fungi become one of the main insect control strategies; treatment with a formulation containing conidia of *B. bassiana* and *T. lignorum* presents insecticidal activity against *A. cephalotes*, with the capacity to be considered a control tool for this agricultural pest (38). In a study applying products such as salicylic acid, boric acid, and sulfur directly onto *Atta sexdens rubropilosa* and *Acromyrmex crassispinus*, control of up to 100 % of these ant species was observed (39).

Control of leafcutter ants should be carried out considering the regional management of this insect. This is because ants can seek leaves over a large area, so control must be carried out by producers in the region, even in urban environments. Control must be carried out comprehensively in the cocoa production area, since if it is not controlled in the surrounding area, they can invade it to collect leaves and cause damage on the farm.

White Grub: *Phyllophaga sp*

The white grub (*Phyllophaga* sp.), belonging to the order Coleoptera, family Scarabaeidae, is the predominant soil pest in Central American crops, affecting cocoa and a large number of crops from different botanical families. The white grub is an insect with a complex life cycle divided into four stages: egg, larva (grub or joboto), pupa (cartridge), and adult (ronrón). The larva develops through three instars; in the third and final instar, it actively feeds on roots for 4 to 5 months, during which time the larva causes the greatest damage to crops. The period when root damage occurs in cocoa plantations is related to the type of white grub species predominant in the cultivation area (40).

One of the most widely used fungi is *Metarhizium anisopliae*, which is easily identifiable by its white coloration, which later turns olive green (25). *Metarhizium* sp. and *Beauveria* sp. for white grub control work by contact, and their effectiveness depends on several fundamental factors: specificity of the applied strains; colonization capacity of protected areas; amount of inoculum present; and predominant soil moisture (41). At the field level, other fungi such as Cordyceps sp. have been found attacking white grub larvae. There are also protozoa, viruses, bacteria, and nematodes that cause insect mortality (25). Adults are controlled by flies of the genus *Pyrgota* sp., which parasitize the beetles in mid-flight, with the fly laying its eggs inside the beetles' wings (25). Insecticides with biological active ingredients such as *Metarhizium* sp. and *Beauveria* sp. for white grub control work by contact, and their effectiveness depends on several fundamental factors: specificity of the applied strains; colonization capacity of protected areas; amount of inoculum present; and predominant soil moisture (41).

Borer Control: *Xyleborus ferrugineus*

The cocoa borer, subfamily Scolytinae belonging to the order *Coleoptera*, is characterized by having species considered pests of economic importance. In cocoa plantations, females of this arthropod can transmit the fungus *Ceratocystis fimbriata*, causing eventual tree death, several months after the initial insect attack (41). Damage is caused by adults, which create numerous galleries independent of each other, although in some cases they may intersect, appearing in a serpentine pattern (42). Females damage branches and the collar area of cocoa trees, making branched tunnels throughout the trunk, cultivating fungi that serve as food for larvae and adults (25).

Among the natural enemies that control *Xyleborus* spp. beetle species are predatory beetles of the family Cleridae, predatory ants, and parasitoids of the families Braconidae, Eulophidae, and Pteromalidae. Among entomopathogens, *Beauveria bassiana* and entomopathogenic nematodes are important pathogens that contribute to the biocontrol of these pest beetles (43-45).

Final considerations on pest control in organic and agroecological systems

The use of biological control agents has increased in agriculture due to the positive results that have been confirmed through research generated in different Latin American countries, which have justified their efficiency in pest control. They are a crucial part of the effort to reduce the use of agrochemicals in agricultural crops because, in addition to their zero impact on environmental pollution, their use has been justified by allowing the development of sustainable and agroecological agriculture, which enables the conservation of natural resources, such as soil and water.

Regarding conservation biological control, cocoa cultivation in agroforestry systems provides economic and ecological benefits through the commercialization of associated plants and the reduction of pest attacks (46). However, diversification must be carried out through the selection of specific plants. For example, *Cedrela odorata*, *Khaya ivorensis*, and *Milicia excelsa* reduced damage caused by mirid pests in cocoa (47). Conversely, Cola nitida and *Triplochiton scleroxylon* increased the presence of mirid pests and the incidence of moniliasis disease (47). Therefore, studies on beneficial plants for use as shade and/or associated crops are important for building highly resilient productive systems.

CONCLUSIONS

Based on this review, it was observed that biological control agents are essential for the management of cocoa crop pests, presenting solid scientific evidence of their effectiveness. For the agroecological control of cocoa crop pests, the use of beneficial organisms is recommended, mainly fungi such as *Metarhizium* sp., *Beauveria bassiana*, and bacteria such as *Bacillus thuringiensis*.

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