CONTROL BIOLÓGICO: UNA ALTERNATIVA DE MANEJO INTEGRADO DE *Trialeurodes vaporariorum* EN INVERNADEROS EN PANAMÁ[1]

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RESUMEN

El control biológico es considerado un componente esencial y viable en el manejo integrado de plagas (MIP) y con el movimiento actual hacia la agricultura sostenible, se espera que juegue una función relevante en el MIP. El objetivo del trabajo fue revisar los esfuerzos de investigación realizados para el manejo integrado de la mosca blanca de los invernaderos *T. vaporariorum*, que afecta la producción de tomates bajo el sistema de cultivo protegido en tierras altas en Panamá. Se revisó la identidad y atributos biológicos de la plaga y sus enemigos naturales, se resumió los estudios llevados a cabo en ellos, así como se documentó los esfuerzos actuales en el control biológico del complejo mosca blanca tanto en cultivos protegidos como en campo abierto. Esta revisión permitió recomendar temas de investigación para el desarrollo de estrategias sostenibles, seguras y eficaces para el control de la mosca blanca que ataca los tomates bajo cultivo protegido en Panamá. La realización exitosa de estas recomendaciones podría proporcionar una alternativa eficaz al control químico, especialmente bajo cultivo protegido, y reducir drásticamente el uso intensivo de insecticidas químicos costosos y tóxicos. También, puede tener aplicación en una amplia gama de cultivos y ofrece insumos para una estrategia de manejo integrado de cultivos con énfasis en Control Biológico bajo el enfoque de Gestión Integrada del Conocimiento y la Innovación, con la participación activa de los principales interesados locales.

PALABRAS CLAVES: Manejo integrado de plagas, control biológico de conservación, parasitoides, artrópodos depredadores, entomopatógenos.

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BIOLOGICAL CONTROL: AN INTEGRATED MANAGEMENT ALTERNATIVE FOR *Trialeurodes vaporariorum* IN PANAMA GREENHOUSES

ABSTRACT

Biological control is considered an essential and viable component for integrated pest management (IPM), and with the current movement towards sustainable agriculture, biological control can be expected to play an even more extensive role in IPM. The objective of this review is to go through the current efforts on biological control of the greenhouse whitefly (*Trialeurodes vaporariorum*), and finally suggest research topics to develop sustainable safe and effective control strategies for whitefly damaging tomatoes under protected cultivation in Panama. The identity and biological attributes of the pest and its natural enemies is reviewed, related studies are summarized and current efforts to biological control of whitefly complex, both protected and open field crops are documented. This review allows recommending research topics to develop sustainable, safe and effective control strategies for whitefly attacking tomatoes in Panama under protected cultivation. Successful completion of these recommendations could provide an effective alternative for chemical control to Panamanian producers, especially under protected cultivation, and sharply reduce the current heavy use of expensive and toxic chemical insecticides. The result may have application in a range of cropping system and offers inputs for a strategy on integrated crop management, emphasizing on Biological Control under Integrated Knowledge and Innovation Management with active participation of the local main stake holders.

KEY WORDS: Integrated pest management, conservation biological control, parasiotids, artropod predators, pathogens.

INTRODUCCTION

The objective of this review is to go through what have been done on this matter and finally suggest research topics to develop sustainable safe and effective control strategies for whitefly damaging tomatoes under protected cultivation in Panama. The general approach is to study and achieve the potential biological control of the naturally present parasitoids in Panama. Successful completion of this objective could provide an effective alternative to chemical control for Panamanian growers and sharply reduce the current heavy use of expensive and toxic chemical insecticides. Moreover, the results will be broadly applicable in view of the importance and wide distribution of this insect pest throughout Central America Region. The result may have application in a range of cropping system. It may help also to establish biological control as a reliable alternative in devising pest management strategies in Panamanian agriculture.

The extensive use of chemical pesticides with the consequent results in development of insect resistance, adverse effects on beneficial insects and wildlife, residues in food crops and associated danger to human health, has increased the demand for the development of environmental and human friendly alternative control measures. One alternative method is the use of biological control agents. Biological control is considered an essential and viable component for integrated pest management (IPM), and with the current movement toward sustainable agriculture biological control can be expected to play an even more substantial role for IPM. As an applied science, biological control often involves releases of exotic natural enemies in an attempt to suppress introduced pest species in agriculture, forestry, and human health, but it is also implemented trough the augmentation or conservation of native natural enemies (Gaugler 2002). Biological control is operationally defined as the action of natural enemies which maintains a host population at levels lower than would occur in the absence of the enemies (Ehler 1990). The development of techniques for biological control can effectively reduce the use of chemicals on field crops and their associated hazards in the environment. Whitefly parasitoids are an addition to the natural enemy's pool and any control management should be integrated, mainly for those where individual strategies alone are inadequate.

Our understanding of the role of naturally present whiteflies parasitoids in Panama is clearly deficient and efforts to integrate specimens identification with pathogenic efficacy criteria should be encouraged, as such studies provide fundamental knowledge useful in increasing our ability to use them effectively for biological control. Moreover biological control with *Encarsia formosa*, which has been successfully used in greenhouse on greenhouse whitefly, *Trialeurodes vaporariorum* turned out to be less effective (Hoddle and Driesche 1996). Selecting more efficient parasitoids for *B. tabaci* B biotype is urgently needed.

Polaszek *et al*. (1992), stated that "A trough taxonomic study of all *B. tabaci* parasitoids is necessary, given the urgent necessity of identifying at least the known species which could be used, in biological control programmes". Hanson (1995) pointed out that our knowledge of parasitoids is limited and there are several current research need such as: 1) to confirm identification of whitefly parasitoids, 2) to determine the efficacy of whitefly parasitoids already existing in their natural agroecosystem.

Information about this will allow us to improve the potential control of naturally present parasitoids against whiteflies in Panama.

Whitefly and its control

The whitefly species, *Trialeurodes vaporariorum*, and *B. tabaci* B biotype (Homoptera: Aleyrodidae) have enormous economic impacts in temperate and tropical regions of the world, damaging many different crops in both outdoor and greenhouse crops (Mound and Halsey 1978, Lenteren and Woet 1988, Perring *et al*. 1993, Brown *et al*. 1995, Menn 1996). Apart from the direct feeding damage, virus transmission and fungal growth on honeydew also cause mayor yield losses. Several sources indicate crop value losses exceeding $500 million annually since 1991 for the United States (Naranjo *et al*. 1998, Perring et al. 1993). In addition to its economic cost, reliance on periodic application of insecticides for whitefly management causes others problems. Several factors within agricultural production systems have contributed to increasing cost of whitefly control (Castle 1999). One problem is the development of widespread of resistance (including cross-resistance) of whiteflies to many commonly used conventional insecticides particularly organophosphates and synthetic pyrethroids (Prabhaker *et al*. 1985, Horiwitz *et al.* 1988, Dittrich and Ernt 1990, Horiwitz *et al*. 2007). Another problem is the decrease or extermination of naturally occurring enemies as a result of excessive use of chemical control (Eveleens 1983), the cultivation of virus-susceptible plant varieties, the movement of infected plant material and the recent emergence of new highly virulent races or biotypes of whiteflies (Brown *et al*. 1995). *B. tabaci* is known to transmit at least 19 plant viruses, including tobacco leaf curl, cassava mosaic and cucumber yellows (Brunt 1986). Today, the prevention of these virus-caused losses by whiteflies is a matter of worldwide high priority (FAO 1994). This worldwide importance of whiteflies as pests is well illustrated by the compilated work by Gerling (1990), Gerling and Mayer (1996), Naranjo *et al*. (1999), listing some 323 references.

Whitefly Biology, Pest Status and Taxonomy

Biology

Whiteflies are small sucking insects (Martin 1987). They are often present in great numbers on the underside of leaves and may be abundant on greenhouse and house plants as well as on wild plants. Whitefly adults lay eggs and immature stages of whitefly develop on the undersides of leaves on most crops

(Byrne and Bellows 1991, Costa *et al*. 1991). Adults congregate, feed, mate, and oviposit on the undersurfaces of the leaves of the host plant. This can occur in such numbers as to create clouds when disturbed, oviposition is heaviest on these leaves. The location on the plant of the various stages of the whitefly follows the development of the plant. Eggs and early instar nymphs are found on the young leaves and larger nymphs are usually more numerous on older leaves (Butler *et al*. 1983, Berlinger *et al*. 1985, Cock 1986). Adult appear to be more active during sunny daylight periods, and do not fly as readily during early morning, late evening, or night hours. The nymphal stages are sedentary, with the exception of the crawler, which after hatching moves over a short distance. Once a feeding site is selected the nymphs do not move anymore. They suck juices from the plant phloem with their piercing-sucking mouthparts. The nymphs are located on the undersides of the leaves and can become so numerous that they almost cover the entire undersurface area (Coudriet *et al*. 1985, Horiwitz and Gerling 1992, Gill 1990, Powell and Bellows 1992a, 1992b).

Injury caused by whiteflies

Direct crop damage occurs when whiteflies feed on plant phloem, remove plant sap and reduce plant vigour. With high whitefly populations plants may die. Whiteflies also excrete honeydew, which promotes sooty mold that interferes with photosynthesis and may lower harvest quality. In some hosts, damage can result from whitefly feeding toxins, which cause plant disorders such as silver leaf of squash and irregular ripening of tomato. Whiteflies, also transmits viruses, such as the geminiviruses in tomatoes, peppers and cabbage (Polston and Anderson 1999). Plant disorders and virus transmissions are of particular concern because they can occur even when a whitefly population is small. In general, the older the plant when infected with virus or the later the onset of plant disorders, the less damage to the crop, so prevention of early development of whitefly populations is critical. Prevention is also crucial in managing whiteflies in crops with high cosmetic value such as ornamental plants, where even low numbers of whiteflies can affect marketability (Hoelmer *et al*. 1991). Excessive *B. tabac*i induced losses worldwide occur in field, vegetable and ornamental crop production. Losses occur from plant diseases caused by *B. tabaci* transmitted viruses, direct feeding damage, plant physiological disorders, and honeydew contamination and associated fungal growth. The number of *B. tabaci* transmitted plant viruses has increased, and total yield losses of important food and industrial crops has occurred (Oliveira *et al*. 2001).

Taxonomy

The recent outbreaks of *Bemisia* sp. (Gennadius) morphotypes has stimulated a renewed interest in whitefly systematics (Perring *et al*. 1993), which was limited until then (Campbell *et al*. 1996). Further, increased international trade and travel are providing additional routes for introduction of exotic species and/or biotypes of whitefly, as well as their parasitoids, on a worldwide scale. The ability to identify closely related but morphological indistinguishable species or atypical morphological strains is critical for determining the geographic origin of a newly introduced whitefly pest and consequently their parasitoids. Knowing the geographic origin is vital to the search for natural enemies used in biological control programs (Gerling 1990). Moreover, early morphological identification of structures of pupal exuviae is important, because the identification of whitefly species is often based on the pupal stage (Gill and Mayer 1996). Mound and Halsey (1978) also noted that pupal case morphology varied on different host leaves and that this has resulted in name synonymy. According to this, Rosell *et al*. (1996) state that polymorphism and plasticity within the global population of whitefly exists to a greater degree than has been documented until now. *B. tabaci* has been recorded from more than 600 plant species and there may be many additional hosts not yet formally documented. Biotypes have been identified in different areas of the world suggesting that *B. tabaci* may be a species-complex undergoing evolutionary change. These biotypes may exhibit differences in viruses transmitted and transmission efficiency, rates of development, endosymbionts, host utilization, and physiological host damage (Oliveira *et al*. 2001). Accurate species identification for both, pest species as well as their parasitoids, is an increasingly important component for the recommendation of appropriate management practices (Neal and Bentz 1999), particularly in biological control.

One approach towards a better understanding of whitefly parasitoids taxonomy is through molecular techniques. Whitefly parasitoids are worthy candidates for molecular phylogenetic analyses to aid in establishing sound higher level taxonomic groups and species identifications because their morphological distinctions are still unclear (Campbell *et al*. 1996). Moreover, a thorough taxonomic study of parasitoids of important whitefly pest species is therefore necessary given the urgent necessity for identifying at least the known species of parasitoids used, in biological control programs or those, which could be, used in the future (Polaszek *et al*. 1992). Ribosomal (rDNA) is present in all organisms, and is composed of several regions (genes and spacers) that evolve at different rates. Ribosomal DNA sequences are suitable for phylogenetic studies at many taxonomic levels: from major lineages of life to intraspecific levels (Hillis and Dixon 1991). At the species and intraspecific levels, the internal transcribed spacer regions (ITS-1 and ITS-2) are often used as a taxonomic tool in many groups such as fungi (e.g. Campbell *et al*. 1993, Hoy 1994; Kuperus and Chapco 1994). The sequencing and restriction analysis of ITS rDNA have been described as promising and/or effective in distinguishing *Trichograma* individuals from different populations (Orrego and Agudelo-Silva 1993, Pinto *et al*. 1997, Sappal *et al*. 1995, Schilthuizen and Stouhamer 1997). Most analyses of relationship have been based on internal and external morphological traits, but molecular techniques are now being applied to understanding the higher phylogeny of the Chalcidoidea and the relationships among species of the genus *Encarsia* between others (Babcock and Heraty 2000, De Barro *et al*. 2000, Campbell *et al.* 2000).

Host Plants of Whitefly

Trialeurodes vaporariorum and *Bemisia tabaci* are highly polyphagous species, currently known from more than 500 species of host plants (Greathead 1986) representing 74 plant families. They have been a particular problem on members of the squash family (squash, melons, cucumbers, pumpkins), tomato family (tomato, eggplant, potato), cotton family (cotton, okra, hibiscus), bean family (beans, soybean, peanuts), Gerbera daisies, salvia, poinsettia, and many other weeds and ornamental plants (Mound and Halsey 1978, Arnal *et al.* 1993). In Panama, Valderrama *et al*. (1994) reported transmission of a geminivirus associated with *B. tabaci* in tomato. Regarding the field of hosts, the virus infected plants of the Solanacea (*Solanum esculentum*, *Nicotiana tabacum* y *Sansum annum*, *Capsicum annum*), Leguminosae (*Phaseolus vulgaris*) and Malvaceae (*Hibiscus esculentum*, *Sida* sp. and *Malachra alcetifolia*) families. Aditionally, Osorio (1998) informed 23 species of weeds as host plants of *B. tabaci* in Los Santos province belonging to the family Asteraceae, Euphorbiaceae, Malvaceae, Solanaceae, Tiliaceae and Fabaceae.

The whitefly problem in Panama

Agriculture in Panama is largely centered in Chiriquí Province, sometimes referred to as the breadbasket of Panama. Although agriculture is diverse, tomatoes and onions are the most important horticultural commodities and the basic staples in Chiriquí, as they are in Central America (González 1998). However tomato yields in Panama are much lower than the potential yield of the varieties that are used. One seriously limiting yields factor is the damage caused by whitefly, which is considered as one of the most important insect pest of this crop in Panama (Gonzalez *et al*. 1994, Sánchez and Serrano 1994). Valderrama *et al*. (1994) reported that since 1991, tomato in Azuero Region is affected by a viruse disease transmitted *Bemisia tabaci*. In addition, in Azuero region, Ferguson (1994) found from population dynamic studies that there are three populations peaks: 1) January/March (weeks 13-21); 2) April/May (weeks 25-30); 3) June/August (weeks 36-45). Biologically based control efforts to date have been very limited due to a lack of effective control agents available for farmers. Chemical control, when used, is usually by application of the acephate, which is a very expensive and dangerous chemical in view of its high mammalian toxicity. The hazard potential is particularly acute in Chiriqui because growers are not trained in the proper application of toxic chemicals. It is common to see farmers wash out a tank of pesticide in a stream also used it for drinking water, washing and recreation. Panama imported approximately 241 million of agrochemicals in 2009 (MIDA). Of these imported agrochemicals, 83% were defensive products, some of them highly toxic insecticides. Regarding insecticidal importation during the last five years, there was an increase in the import of insecticides by the order of 3%, resulting on one hand, capital flight and in the other an increase in production costs (González *et al*. 2009). Moreover, there are potentially more risk of an indiscriminate use of pesticides which might cause environmental problems and represent a global concern. There are, however, few alternative technologies available for farmers for whitefly control. Historically very little has been done in Panama to develop or improve technical knowledge about the ecological interrelationships and its effect on agricultural productivity, since its economy has been based mainly on the service sector. The National Institute for Agricultural Research has increased information on environmental effects of agriculture and pest control during the last 10 years i.e. compared research done in 1984 and 2010, there has been an increased on the priority of friendly alternative research in crop protection from 20 percent to 90 percent. Nevertheless more effort needs to be done, in order to get growers aware of alternatives for chemical control.

Information from Central America and Panama species of whiteflies parasitoids is sparse (King y Saunders 1984). Mound and Halsey (1978) wrote and excellent but short report on Panamanian species, it discusses only four species (out of 1156 species worldwide) that inhabit in Panama, within four genera and two families. Nonetheless, the worldwide distributed genus *Bemisia* and species of *Trialeurodes vaporariorum* are not indicated to be present in Panama by these authors. It is known from the literature that *Bemisia* B biotype is actually present in Panama (Brown *et al*. 1995), and more recently, Name (2000) indicate as a result of a survey in Chiriqui province, a preliminary distribution of the species *Trialeurodes vaporariorum* and *Bemisia tabaci* of which, *Bemisia tabaci* was the predominant whitefly species in the lowlands, and *Trialeurodes vaporariorum* is more abundant at higher altitudes (above 1200 m). *Bemisia tabaci* biotype B in the lowlands was also found by Fernandez 2001[4]. *Bemisia tabaci* biotype B is polyphagous, attacks a range of glasshouse and field crops, and often causes phythotoxic damage (CABI 1999a, 1999b). In Central America, 14 species within 10 genera in two sub-families (Aleurodicinae and Aleyrodinae) of whiteflies have been reported: *Paraleyrodes* sp., *Ceraleurodicus altissimus, Aleurodicus cocois*, *Aleurocanthus woglumi*, *Dialeurodes citrifolii*, *Tetraleurodes mori*, *Tretraleurodes abutiloneus*, *Trialeurodes vaporariorum*, *Trialeurodes floridensis*, *Bemisia tabaci*, *Trialeurodes variabilis*, *Aleurothrixus floccosus*, *Aleuroplatus* sp., *Trialeurodes acaciae*.

Natural Enemies of Whitefly

The main groups of whiteflie natural enemies are predators, pathogens and parasitoids.

Predators. About 75 species prey upon whiteflies, especially general predators such as spiders, beetles, etc. Individual predator species in the families Anthocoridae, Coccinellidae, Chrysopidae, Hemerobiidae and most of the Miridae are unable to maintain greenhouse whitefly numbers below damaging levels, although inundative releases of a complex of predators may do so (Heinz 1996). Some predatory bugs in the genera *Macrolophus* or *Dicyphus* can sufficiently reduce whitefly populations (Onillon 1990), although some also damage plants. In warm climates, where greenhouses often have large ventilation openings, generalist predators move in naturally and may cause considerable mortality of whiteflies.

Pathogens. In general, pathogens of insects belong to very different taxonomic groups like viruses, bacteria, protozoa,

[4]Fernández, O. 2001. Department of Virology (interview). IDIAP (National Institute of Agricultural Research). Panama. Panama.

rickettsiae, fungi and entomophagous nematodes. The spectrum of whitefly pathogens is narrow. There are no records of nematodes parasitizing whiteflies. While it is possible that viruses or bacteria kill whiteflies, this is mainly due to secondary infections by entrance through existing wounds. So far, the pathogens reported from Aleyrodidae have been exclusively fungi, because only they are able to infect these plant-sucking insects by penetrating the cuticle. Four genera of fungi attacking whitefly are regularly mentioned in the literature: *Beauveria*, *Aschersonia*, *Lecanicillium* a genus formerly known as *Verticillium* and *Isaria* also formerly known as *Paecilomyces* (Vega *et al.* 2009). Entomopathogenic fungi infest their aleyrodid hosts by penetrating the cuticle after the conidiospores germinates. Subsequently, various fungal structures are produced, which circulate in the haemolymph, invading the insect's organs and probably producing lethal toxins (Fransen 1990). One major limitation of entomopathogenic fungi as biological control agent is their needs for high humidity to germinated and infect the host (Lacey *et al*. 1995). Another limitation comprises the restrictions placed on the use of so-called exotic strains that could harm non-target organisms (Lacey *et al*. 1995).

Two categories of fungi that attack whitefly can be distinguished: fungi specialized on Aleyrodidae like *Aschersonia* spp. and *Conidiobolus* spp. (Fransen 1990, Gidin and Ben Ze'ev 1994). And broad-spectrum fungi, containing various genera like *Beauveria*, *Lecanicillium* and *Isaria*, which can infect insects belonging to different orders.

Aschersonia fungi have an essentially tropical and sub-tropical distribution. They have been successfully applied and established to control whiteflies on citrus and additionally, they have been tested against the greenhouse whitefly in glasshouses of Central and Eastern Europe and some Oriental countries (Fransen 1990). *Aschersonia* isolates may kill up to 90% of *T. vaporariorum* and *B. tabaci* B biotype Bellows and Perring at greenhouse experimental conditions (Meekes 2001). *Aschersonia* spp. equally attacked *T. vaporariorum* and *B. argentifolii* Bellows and Perring and caused the same mortality levels for both whitefly species (Meekes *et al*. 1996). In fact, each fungus that is introduced to control *Bemisia*, will almost certainly affect *T. vaporariorum*.

Most research has been done on *Beauveria*, *Lecanicillium* and *Isaria* because they are broad-spectrum fungi, and therefore, more attractive for commercial production. *Lecanicillium lecanii* (Zimm) Viegas seems promising for controlling greenhouse whitefly, although an effective infection requires high relative humidity but moderate temperatures (Ekbom 1979). *Isaria fumorososeus* var. *beijingesis* attacks *T. vaporariorum* on glasshouse cucumbers at moderate temperatures and high relative humidity (Fransen 1990).

So far *Aschersonia* is more difficult to produce commercially than the other fungi. It takes 14 days to mass-produce *Aschersonia* spp. spores, whereas it only takes five days to produce millions of *Beauveria* spores. Using fungi to control insects is not only a question or using the best fungus species, but also a question of using the best commercial formulation (Meekes 2001[5]).

When reporting these fungi's interactions with other natural enemies, Fransen (1990) observed that populations of the parasitoid *E. formosa* Gahan survived treatments with *Aschersonia aleyrodis* Webber and adult parasitoids did not become infected. *E. formosa* females may even help with fungal transmission by probing infested hosts, carrying fungal structures on their oviposition and injecting uninfected hosts. *Lecanicillium lecanii* did not directly infect the parasitoid *Amitus fuscipennis* when they were tested together on *T. vaporariorum*, but the fungus seemed to decrease the parasitoid's parasitic activity (Pachón and Cotes 1997).

Parasitoids. About 100 species of whitefly parasitoids are known and more species are expected to be found. Most of the parasitoids are very host specific, but some species are hyperparasitoids and their importation might reduce the efficiency of primary parasitoids, e.g. *E. pergandiella* Howard in New Zealand. Many important whitefly parasitoids belongs to the genus *Encarsia*, family Aphelinidae (Lenteren *et al*. 1997). They show a wide variety of reproductive behaviour (Gerlings 1990). Some species, like *E. formosa* are primary thelytokus parasitoids, *i.e.* females are produced on a phytophagous host insect parthenogenetically. Other *Encarsia* species are also primary parasitoids, but produce haploid males from unfertilized eggs and diploid femeles from fertilized eggs, i.e. they are arrhenotokus. Still other species are arrhenotokous hyperparasitoids and they produced males and femeles by laying eggs in other, inmmature parasitoids of a different species. Further, species are known where

[5]Meeke, E. 2001. Laboratory of Entomology (interview). Wageningen University. The Netherlands.

one sex, usually the female, develops as a primary parasitoid, and the other sex, the male, develops hyperparasitically on their own or another species of parasitoid, *i.e.* heteronomous hyperparasitoids or facultative autoparasitoids.

It has been extensively demonstrated in inoculative and seasonal inoculative biological control that introductions with individuals of one parasitoids species and particularly with *E. formosa* - are sufficient for economically feasible whitefly control (Gerling 1990). In warm climates, like the Mediterranean area, parasitoids of whitefly may immigrate into greenhouses and provide natural pest control. During the past years others parasitoids have been tested and used to control whiteflies, like species from the genera *Eretmocerus* (Hymenoptera: Aphelinidae) and *Amitus* (Hymenoptera: Plastygasteridae).

Whitefly Natural Enemies in Panama

Russell (1962) describes natural enemies of whiteflies found in Panama of the genera *Encarsia*, *Eretmocerus* (Chalcidoidea: Aphelinidae) and *Amitus hesperidius* Silvestri; *Amitus* sp.; *Amitus hesperidius* var *variipes* Silvestri (Proctotrupoidea: Plastygastenidae). Carreiro (1994) reported *Eretmocerus*, *Encarsia* and *Aleurodiphilus* (Aphelinidae) as *Bemisia tabaci* parasitoids; being *Eretmocerus* the most abundant for tomato grown under field conditions in the southern region known as Azuero (Ferguson 1994, Bernal 2001). More recently, Gonzalez *et al*. 2009 reported the genus: *Encarsia* (*E. bimaculata*, *E. hispida*, *E. pergandiella/ tabacivora*, *E. porteri*, *E. nigricephala*, *E. citrella*, *Encarsia* sp.), *Eretmocerus* (*E. eremicus*, *Eretmocerus* sp.), *Amitus (Amitus* sp.), and a hyperparotoid *Signiphora* (*S. aleyrodis*). Other than this, little is known regarding local data about biology of these parasitoids and their efficiency in controlling whiteflies (Hanson 1995).

Whitefly management methods

The management of insect pests rarely relies on a single control practice; usually varieties of tactics are integrated to maintain pests at acceptable levels. The goal of integrated pest management is not to eliminate all pests; some pests are tolerable and essential so that their natural enemies remain in the crop. Rather, the aim is to reduce pest populations to less than damaging numbers. The control tactics used in integrated pest management include pest resistant or tolerant plants, and cultural, physical, mechanical, biological, and chemical control. Applying multiple control tactics minimizes the chance that insects will adapt to any one tactic. The definition for integrated pest management most relevant comes from

Flint and Bosch (1981): "An ecologically based pest control strategy that relies heavily on natural mortality factors and seeks out control tactics that disrupt these factors as little as possible".

Integrated pest management requires an understanding of the ecology of the cropping system, including that of the pests, their natural enemies, and the surrounding environment. Knowledge about the ecological interrelationships between insects and their environment is critical to effective pest management.

In natural ecosystems and agroecosystems where pesticides are not used, an array of natural enemies usually keeps whiteflies at low numbers: predators, parasitoids and pathogens are all influenced. Studies in two cropping systems, tomatoes in the 1960s in California and cotton during the period 1925-1992 in Sudan, has shown that whiteflies can be kept under perfect natural control (Lenteren *et al*. 1996). However, when pesticides are applied, natural enemies are exterminated resulting in whitefly pest outbreaks, in the above mentioned cases *T. vaporariorum* and *B. tabaci*, respectively.

In protected crops, the low tolerance of pest insect is reflected by widespread and frequent use of insecticides. Nowadays, the risks to man and environment and the problem of development of resistance against insecticides by insects (Dittrich and Ernt 1990) are recognized and alternatives are being considered. Years ago, development of resistance to certain pesticides is reported of *T. vaporariorum* and *B. tabaci*, as well as acceleration or resurgence of whitefly populations through chemicals (Wardlow *et al*. 1976; Dittrich and Ernt 1990). Therefore, non-chemical control methods of whiteflies pests are being looked for. Monitoring of whiteflies is used to trace the insects in a crop and to keep a record of their presence. Alternative control methods are, for example, integrated pest management and breeding for host plant resistance to insect. Biological control of whitefly (*T. vaporariorum*), an element of integrated pest management, may offer a possibility and several methods can be followed (Lenteren *et al*. 1996):

(1) Conservation biological control gives emphasis to the preservation and enhancement of natural enemies and is the basis of all approaches to biological control. Conservation of natural enemies is often credited with being the oldest form of biological control. However, compared with classical and augmentation biological control it has received relatively little attention as a method

of arthropod pest suppression (Ehler 1998). It can be broadly categorized into three overlapping components which encompass survey and potential of extant natural enemies, elucidation and manipulation of factors constraining or enhancing natural enemy abundance and activity, and evaluation of biological control efficacy (Naranjo 2001).

(2) The inoculative release method. Beneficial organisms are collected in a region from which the pest insect originates and introduced in relatively small numbers in a region where the pest was introduced. The aim is a long term control effect and the method has been successful when a continuous existence of the natural enemy was possible (Onillon 1990).

(3) The inundative release method. Beneficial organisms are released periodically in large numbers in a crop for immediate control. This requires mass rearing of the natural enemy. Illustrating examples are the release of *E. formosa* against *B. tabaci* in poinsettia and the application of entomopathogenic fungi against *T. vaporariorum* (Albert 1990, Fransen 1990, Meekes 2001).

(4) The seasonal inoculative release method. This method differs essencially from the above mentioned inundative releases in the fact that buildup of the natural enemy population for control later during the same season is pursued. Thus, it requires several generations of natural enemies and pest insects in a crop. The approach is successfully applied in the control of *T. vaporariorum* by *E. formosa* in protected tomato crops (Lenteren and Woets 1988).

Any control method alone is not able to manage with the complex problematic situation described above. Futhermore, many of the management strategies are applied without taking into account local knowledge, farmer's perceptions and other actors' initiatives in rural areas (Santamaría Guerra 2012). In the framework of the contextual theory of action, Integrated Knowledge and Innovation Management, from a holistic, systemic and committed to the context of its application and implications perspective offers alternatives to the need to improve efficiency and relevancy levels of development organizations and their contribution to a productive and institutional innovation (Santamaría Guerra 2011).

Final Recommendations for the Integrated Pest Management Research

As advanced previously this review allows recommending research topics to develop sustainable safe and effective control strategies for whitefly attacking tomatoes in Panama under protected cultivation. Moreover, the results will be broadly applicable in view of the importance and wide distribution of this insect pest throughout the country. The result may have application in a range of cropping system. It may help also to establish biological control as a reliable alternative in devising pest management strategies under protected cultivation in Panama.

The following research activities should be implemented

1. Identification of the most abundant whitefly pest species present in tomato in Panama.
2. Identification of the most abundant naturally present parasitoids of whiteflies in tomato and other host plants in Panama.
3. Review, develop and apply identification molecular techniques on the important pest's parasitoids species of whiteflies based on the PCR technique.
4. Describe the basic life history parameters of the most important whitefly pest species and their natural enemies.
5. Determine the population dynamics of the most important whitefly pest species in Panamanian greenhouses.
6. Determine and compare efficiency of *Eretmocerus* sp. (Chalcidoidea: Aphelinidae), a naturally present parasitoid genus in Panama.
7. Present a proposal of a strategy on integrated tomato crop management with emphasis on Biological Control under Integrated Knowledge and Innovation Management with the active participation of the local main stake holders.

Rational choices regarding pest management strategies require by definition a thorough understanding of the basic life history parameters of the insect pest. Present information on whitefly pest species of whitefly is inadequate in Panama to implement any control strategy, chemical, biological or other. Since control efficacy can vary with life stages and whiteflies species, a study of all life stages of the whitefly pest species is necessary. Further, optimal application of any control agent requires the capability of predicting patterns of abundance (temporal and geographical). Information derived from the above recommendations will serve the dual function of (1) providing a basis for biological control, (2) providing the framework for the development of contextual managerial strategies.

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