Chapter 6

Aleurocanthus woglumi (Hemiptera: Aleyrodidae) in *Citrus*: Opportunities and Challenges to Implement a Sustainable Management

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Abstract

Citrus BlackFly (CBF) always represented a threat to Brazil. The impact of the introduction in Brazil of the CBF has led to serious economic and environmental consequences. In this chapter, we will show relevant information on biological aspects, history of occurrence, and impact of CBF on *Citrus* in Brazil; data about dynamics populations and spatial distribution patterns and dependence will be presented. We are intending to emphasize in this chapter the main challenges and opportunities of some important tactics to promote sustainable management of CBF in citrus, such as: (i) biological control, (ii) chemical and others methods, and (iii) induced resistance.

Keywords: citrus blackfly, sampling, biological control, insecticides, induced resistance, integrated management

1. Introduction

In the southern hemisphere, Brazil dominates a great part of the orange production [1]. Besides the production of fruit, the main destination is orange juice industry, Brazil being one of the largest producer and exporter of that drink in the world [2]. Nevertheless, there are several problems associated with some stages of the production chain, but in plant production the main obstruction is the occurrence of Citrus BlackFly (CBF) *Aleurocanthus woglumi* (Hemiptera: Aleyrodidae) [3]. Though they can be seen in a wide range of plants, their main hosts are the genus *Citrus*, which is economically important [4].

In Brazil, CBF is considered as one of major pest introduced in *Citrus* and has spread surprisingly over the various regions of the country [3]. CBF adults and nymphs are phloem feeders, which cause direct damage to plants by ingesting large quantities of plant sap. In addition, they produce copious amounts of honeydew, which facilitate the growth of sooty mold on leaves and fruits. This causes a reduction in the photosynthetic capacity of the plant, and fruits are rendered unmarketable [5]. Production losses are estimated in the range of–80% [6].

CBF was first detected in the Nagpur region of Maharashtra (India) in 1910 by Woglumi. In 1915, it was reported in the rest of Asia by Ashby. [7]. In 1913, it was discovered in the New World and in West Indies in 1913 from where it spread out to other islands and Central and South America [8]. On the American continent, it was first discovered in Jamaica in 1913. Between the years 1934 and 1935, it was detected in Cuba, Florida, and Mexico. In Brazil, this insect was first detected in the state of Pará, in 2001 [9]. In 2007, CBF was officially included in the quarantine pest list of Brazil. But due to the extensive spread, this insect was excluded from pest quarantine list Brazil, after losing its quarantine character (Normative Instruction (NI) no. 42, the Ministry of Agriculture, Livestock and Supply (MAPA)). Register of CBF occurrence already was realized in these following Brazilian states: Amazonas, Bahia, Ceará, Espírito Santo, Goiás, Mato Grosso do Sul, Maranhão, Pará, Paraíba, Paraná, Pernambuco, Piauí, Rio de Janeiro, Rio Grande do Norte, Rondônia, Roraima, São Paulo, Sergipe, and e Tocantins [10].

The Plant Transportation Permission–PTV is an official document issued to monitor the transit of starting plants, parts of plants, or plant products produced in accordance with the standards of plant health protection in order to prevent the spread of pests regulated, as stated in the Normative Instruction 54, of December 4, 2007, of the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA). In Brazil, CBF restricted transport of more than 31 vegetable species considered hosts to the pest, which required the issuance of PTV for the transit of these products when transported from a state where the pest is present to another state that did not had its occurrence. Since it is wide spread, on February 20, 2015, the NI no. 2 of MAPA established that currently there is no restriction on the interstate transit of plants and their parts. Transportation of fruit seedling and infested leaves is the main way for the spread of this pest to long distances [11]. The fast spread must have been facilitated by river and road transport, especially on *Citrus* fruits from occurrence areas of the insect to juice industry concentrated areas like São Paulo State [3]. After detection in the state of São Paulo, CBF population became a prominent pest on infested citrus orchards, including sweet orange (*Citrus sinensis*), mandarin (*Citrus* spp.) and Tahiti acid lime (*Citrus latifolia* Tanaka) [11].

Since there are a large number of arthropod pests infecting *Citrus*, some vectors of destructive diseases, chemical control has been used in Brazil, often without technical criteria, causing undesirable side effects. In general, *Citrus* in Brazil, mainly in big areas like in São Paulo State, is highlighted as it is both a major source of income and jobs and due to the difficulty in the control of pests and diseases that occur in cultivation [4]. In some parts of the world, CBF has been successfully controlled using alternative control methods, especially biological control [5]. In some cases, biological control is more effective than chemicals to control CBF populations. In Brazilian *Citrus* orchards, there are some candidates for the biological control of the

CBF. In addition, others strategies like induced resistance and natural insecticides are promising. In this chapter, we are emphasizing the main challenges and opportunities to use some important tactics to promote management of CBF in *Citrus* with sustainability, in addition we are addressing some perspectives focusing in what, when and/or how use each one of tactics.

2. Dynamics populations and dispersal pattern

The knowledge about major infestation potential of CBF and its seasonal dynamics is essential for the orientation of management strategies, which may result in the minimization of production losses [12]. Because with use of CBF sampling, it is possible to prevent outbreaks of the pest and to decide only when necessary. In others words, the tactics of control such as use of chemicals or similar or release of natural enemies will be realized only on the recommended thresholds. The variation in climatic variables, especially temperature and rainy season, is important on infestation potential of CBF [13]. In general, the highest population levels of CBF occur in the low-precipitation season [14, 15]. But in Municipality of São José de Ribamar, State of Maranhão (Brazil), in a commercial orchard of *C. latifolia*, the average total number of citrus blackflies was higher during the rainy season than in dry season [16].

In a bioclimatic simulation in the North region of Brazil, the optimum bioclimatic zone was established between October, November, and December. In general, summer is favorable for the occurrence of CBF in the South Hemisphere; that is, winter is unfavorable [12]. In Minas Gerais and north of São Paulo, the optimum time is in December and unfavorable months are July, August, and September, a similar pattern may favor the spontaneous migration of the insect between these sites [12]. In Municipality of Artur Nogueira, State of São Paulo (Brazil), with one year of evaluation the peak occurrence of egg was observed in the spring (August) and for nymphs in the autumn (from March to May) in a commercial orchard of *C. latifolia* [11].

Females of CBF prefer oviposition sites of the canopy with high humidity [11]. But the distribution pattern intratree shows difference between geographical regions and between years and seasons. In an experiment conducted in São Paulo State, the trees were divided in four quadrants (north, south, east, and west), the western quadrant showed more CBF egg masses than the northern, but no difference was observed in the southern and eastern quadrants. Western and eastern quadrants showed highest quantities of CBF nymphs [11]. However, in another experiment in State of Maranhão, Brazil, it was observed that during rain period the insects (eggs and nymphs) were distributed homogeneously on the trees canopies in a commercial orchard. In addition during the period without rain, the north and south quadrants showed less clutches/plant, eggs/plant and nymphs/plant in a non-commercial orchard and clutches/plant, eggs/plant in a commercial orchard [15]. The infestation level may vary in accordance with the crop system, because there is evidence that infestation of CBF is different in agroforestry and conventional system [13].

Upon adjusting the calculated variograms to the spherical model in the dry and rainy seasons [16], it was concluded that the spatial distribution of CBF in the orchard is aggregated, but the level of average aggregation depends on the weather especially during the season, during the rainy season the average aggregation is 162,092 m^2, and 9615 m^2 in the dry season. They recommend to obtain a reliable estimate of citrus blackfly populations, at least one trap should be used for each 17 hectares during the rainy season and one trap per hectare in the dry season. Silva et al. [17] used a similar approach of spatial dependence described by the spherical model; that model has a simple polynomial expression and its shape had an almost linear growth up to a certain distance and then stabilized. Silva et al. [17] confirmed that spatial distribution of CBF in citrus orchard in the agroforestry field in Pará State was predominantly aggregate, forming clusters from 15.5 to 34 m. This aggregation behavior of CBF increased the initial damage in newly infested orchards [11].

In a general way, some studies have showed evidence of an aggregation behavior of CBF on a spatial scale. In terms of sampling methods to implement this component of CBF IPM, it is interesting to know how the population dynamics is in intratree distribution and in spatial scale of different landscape structures, because some differences of results found about the occurrence of CBF should be considered according to the kind of pest management and the degree of landscape heterogeneity. We would like to encourage future studies about dynamics populations of CBF in a period longer than 2 years of evaluations that may consider spatial mathematical modeling and/or use of statistical models as generalized linear mixed models with overdispersion for helping to understand this cluster behavior and temporal and spatial dispersal patterns according to the landscape structure of *Citrus* orchards.

3. Biological control

The use of beneficial organisms as a component of integrated pest management (IPM) is relevant for most crops [18, 19]. The search about natural enemies associated with CBF has enabled the use of biological control worldwide. One of the most effective parasitoids of the CBF is *Encarsia perplexa* Huang & Polaszek (Hymenoptera: Aphelinidae) [20]. *E. perplexa* was originally misidentified as *Encarsia opulenta* (Silvestri) (Hymenoptera: Aphelinidae) but was later identified to be *E. perplexa*. When the adult parasitoid emerges from the blackfly pupal case, it leaves a roundish black hole. Normal emergence of a CBF adult would leave a T-shaped split in the pupal case [20]. Biological control of CBF, especially with predators of genus *Ceraeochrysa*, *Chrysopa*, *Chrysoperla*, and *Delphastus*; and parasitoids of the genus *Calles*, *Encarsia*, and *Amitus* have been indicated to maintain the CBF population below of the economic threshold [21–23]. *E. perplexa* already was released for the control of CBF in Mexico [24], Texas [25], and Florida [26]. The parasitoids *Amitus hesperidum* Silvestri (Hymenoptera: Platygasteridae) and *E. perplexa* were introduced in the United States in 1996 by the Ministry of Agriculture of the United States, in collaboration with the United States Department of Agriculture. Nearly 49,000 *A. hesperidum* and 165,000 *E. perplexa* were released in 1996–1997 [5]. Continued control of CBF requires sustained releases of *A. herperidum* in South Texas, because it is unable to survive the severe summers of that region [27].

The parasitoids *A. hesperidum* and *E. perplexa* have kept CBF populations under effective biological control in Dominica [5, 28]. In effective control program of the CBF, with field multiplication and redistribution, a total of 573,000 parasitoids were produced and released in various *Citrus*-growing areas of Dominica [28]. In another release program of *A. hesperidum*, *E. perplexa* in Dominica, after 4 years of the release for the classical biological control of the CBF, these two parasitoids were found at the site where CBF was encountered and pest populations were declining [5]. In addition, Lopez et al. [5] believed that there is no evidence of any nontarget effects on other Aleyrodidae or their natural enemies, because the two parasitoids were not among the several species collected on nontarget Aleryodidae and Hemiptera.

The solitary endoparasitoid *E. opulenta* is also a promising biocontrol agent for population regulation of CBF in several countries [29]. However, the assessments of the different aspects of the biology and behavior as well as its effectiveness to be released are still necessary. Satisfactory parasitism levels were observed with *A. hesperidum* in inundative releases in Trinidad and Tobago [30]. In Pará, there has been an increase in parasitism by microwasps which was not identified, with parasitism reported up to 90% [31]. In Rio de Janeiro, for the first time, the association of *Encarsia pergandiella* Howard (Hymenoptera: Aphelinidae) acting as a parasitoid of *A. woglumi* nymphs infesting *Citrus latifolia* leaves was recorded [32].

The natural enemies of Chrysopidae family, known as lacewings, are predators that play a significant role for controlling the population of the blackfly on various crops of agricultural importance such as cotton *Gossypium hirsutum* preying *Heliothis* spp. (Lepidoptera: Noctuidae) and on tomato *Solanum lycopersicum* preying *Bemisia tabaci* B biotype. The potential of these predators to reduce the population of many pests is a factor, which has been reported by several researchers as promising on control of CBF [23, 33]. As well as the occurrence of species *Chrysopidae* (Neuroptera) [32] was common, and the species of *Coccinellidae* (Coleoptera) was also recorded as the natural biological control of CBF in *C. latifolia* orchards in Brazil. In fact, species of *Chrysopidae* and *Coccinelidae* (Coleoptera) are important in the control of CBF, for example in the north region of Brazil, 11 species of *Chrysopidae* and *Delphastus pusillus* (Le Conte) (Coccinelidae) were observed preying CBF [11, 34, 35].

In the last few years, a strong effort has been made to improve techniques for rearing of natural enemies of CBF in laboratory by some Brazilian University Laboratories. The main challenge to release natural enemies on a large scale to biologically control CBF in Brazil is the absence of commercial availability of these natural enemies yet. But a promising perspective of applied biological control will probably happen with government partnerships like Bahia State, Brazil for mass production of CBF's natural enemies [37].

4. Chemical insecticides and other methods

Chemical insecticides have been used to control its infestation; however, this strategy reduces the insect pest of infestations only temporarily triggering the imbalance in the environment that in turn, poses threat to nontarget organisms [19, 36]. Evaluations about the effect of Dursban 4E [chlorpyrifos] in two different nursery locations by Ref. [37] showed that they observe only limited control, and this product was not phytotoxic to nursery citrus. Monocrotophos (0.05%) was effective to promote nymphal mortality (range from 75.10 to

85.50%) of CBF [38]. They believe that application of monocrotophos (0.05%) during early nymphal stages followed by neem oil (1%) during later stages may be effective and also safe to parasitioids.

In Brazil, four insecticides are registered to control this pest in *Citrus*, three neonicotinoids with the active ingredient imidacloprid and a technical mixture based on anthranilamide [chlorantraniliprole] with lambda-cyhalothrin [pyrethroid] [39]. Synthetic insecticides should not be sprayed when much of the blackfly population is in the adult stage; therefore, it is recommended to wait 10–12 days for the decrease in adult population allowing the young stages (egg and nymphs) to emerge which can be controlled before they cause damage [40].

In the Texas (USA), it is common that organic growers apply pesticides such as sulphur, oils, and microbials to CBF control [27]. In particular, in the region of Borborema, State of Paraiba, the farms consist of highly diversified systems, with high abundance of natural enemies. The citrus areas are usually in a highly diversified landscape along with the annual crops (e.g., *Manihot* spp.), others fruit species or agroforestry, in the intercropping system or in the neighboring. The landscape diversification is an important cultural practice in pest management and is based on the principle of reducing insect pests by increasing the diversity of an ecosystem by the presence of more than one plant species. Studies indicate that diversification practices such as intercropping in the northeast region are beneficial because these practices reduce pest damage [41]. But when applied to *Citrus*, it is still necessary to understand how the occurrence of natural enemies associated with CBF differs in a landscape with the diversification system compared to the monocrop system in the northeast region. In addition, the most families in the region do not use pesticides. The use of chemicals insecticides must be analyzed judiciously, especially in small areas because according to the reduced size of the property and proximity of homes with orchards, it is possible that the drift of chemical insecticides can reach locations other than target of applications such as the vicinity of houses, animals, small and local food supply, and water reservoirs [42].

The use of mineral oil, vegetable oils, or derivatives may result in improved control strategies for agricultural pests and associated diseases and can cause minimal adverse effects on populations of natural enemies and other non-target species [43, 44]. Therefore as an alternative to chemical control, potential alternative products have been the subject of study by the group of researchers from the Federal University of Paraíba–UFPB [43, 44]. The interesting result is that some vegetable oils were effective and promoted ovicidal activity [42], for example, it is observed that cottonseed oil provided 100% egg mortality. Oils from *Eucalyptus globulus* Labill, *Allium sativum* L., *Ricinus communis* L. are a promising alternative to control *A. woglumi*, especially between 10 and 15 days after application of these products, the mortality of eggs is near to 90–100% [44]. These and other results are summarized in **Table 1**, indicated the effect of some oil from plants applications on the mortality of the CBF. We could separate in some intervals of mortality observed. Other treatment like gamma irradiation [45] is also showed.

In general, the use of chemical control for of CBF mentioned in this section should ultimately be used because it is too costly and inefficient [19], especially when performing on the clutches

Activity on insect stage	Treatment (concentration or dose) [source]
Treatment with product from plants	
Mortality on egg (90–100%)	Rott Nim® (1.5%), oils from *Glycine max* (0.5–1.0%), *Helianthus annuus* (0.5–1.0%) and *Gossypium hirsutum* (1.5%) [43]. Oils from *Eucalyptus globulus* (4–6%), *Allium sativum* L. (4–6%), *Sesamum indicum* L. (6%) and *Ricinus communis* L. (6%) [44]
Mortality on egg (60–89%)	*Zea mays* oil (0.5%) [43]. *Dianthus caryophyllus* L. [44]
Mortality on egg (40–59%)	Extract from *Piper aduncum* L. [63]
Mortality on nymph (90–100%)	Oils from *Glycine max* (1.5%), *Zea mays* (1.5%), *Helianthus annuus* (1.5%), *Gossypium hirsutum* (1.5%) and Rott Nim® (1.5%) [43]
Mortality on nymph (50–70%)	Neem oil (1%) [38]
Treatment with irradiation	
Mortality on egg (90–100%)	Gamma irradiation (200 Gy) [45]

Table 1. Summary of some alternative treatments from plants and with irradiation on mortality of citrus blackfly stages.

of this insect. In addition, high-dispersion by means of the adult flight favors the fast infestation of plants and orchard and cross infestation among citrus and other hosts and between neighboring groves [10]. This probably has hindered the effectiveness of chemical control because of the ease of reinfestation, especially in abundance of host sites. In Brazil, many are the hosts of the blackfly [4]. In Rio de Janeiro, for example, recently–three new host plants for *A. woglumi* were identified: *Artocarpus heterophyllus* (Moraceae), *Pouteria caimito* (Sapotaceae), and *Struthanthus flexicaulis* (Loranthaceae) [32]. In spite of the use of various substances as alternative to the synthetic insecticides, insect pests are destructive especially in small farms that produce fruit [46, 47], but for a precise recommendation the use of these substances, future studies should validate their efficiency in field and their compatibility with others tactics as biological control.

5. Induced resistance in citrus with silicon

Resistance induction corresponds to activation of the latent defense system in plants when they come in contact with compounds called elicitor agents. Among the elicitors, silicon has attracted the attention and interest of researchers. In addition to providing resistance, it may also provide nutritional benefits and increase the production and quality of agricultural products. The resistance induced by silicon is expressed in various ways, such as cell wall lignification, papillae formation, or induction of various defense proteins [48].

The use of silicon for the induced resistance of plants is a potential strategy in the integrated pest management, however this substance has not being considered as an essential nutritional element to the plants [49], but as potassium silicate, calcium silicate, and sodium silicate from other sources has determined the tolerance of many plant species to insects [50–53]. Silicon promoted cuticle thickening and accumulation of crystals on the leaf stomata in sugarcane [54]. The action of silicon may not be only restricted to resistance constitutive or induced but may also involve induced plant chemical defense [51].

Inducing agents sensitize the plant to activate their defense mechanisms in response to the presence of pests. These mechanisms may involve enzymes such as peroxidase, β-1,3-glucanase, chitinase, phenylalanine ammonia lyase, and polyphenol [55]. The peroxidase activity has been implicated in a variety of processes pertaining to the protection of plants, including hypersensitivity reaction, lignification, and suberization [56]. Hypersensitivity reaction is characterized as a fast and localized response. Among the main characteristics of the possible responses are the rapid and localized collapses of plant tissue around the site of infection, caused by the release of toxic compounds, which also act in some cases, directly on the pathogen, causing mortality. Structural barriers may involve lignification and suberisation and can be seen as physical defenses that restrict the development of insect pests. The lignification is a biochemical process that covers monolignol biosynthesis, transport, and polymerization in the cell wall, which in the first stage is highly mediated by enzymes intrinsic to the formation of the forerunners in the cytoplasmic compartments. The second stage is the formation of lignin in the cell wall. The oxy-reducing enzymes such as peroxidases and corresponding isoenzymes, act in the polymerization of lignin in the cell wall, forming a coordinate complex with hydrogen peroxide [57]. The deposition of lignin increases the resistance to the cell wall digestive enzymes of the insect pests. This resistance is also enhanced with presence of suberin or deposition of suberin lamella covering the cell wall of this process is called suberization.

Peroxidases participate in various physiological processes by catalyzing the oxidation and polymerization of hydroxycinnamic alcohol in the presence of hydrogen peroxide, resulting in lignin, an important physical barrier of plant defense [58], which contributes to strengthening the cell walls of the host. Changes in peroxidase activity by treatment with elicitors may indicate their involvement in resistance in plant induction [59]. Phenylalanine ammonia-lyase plays a fundamental role catalyzing the conversion of L-phenylalanine to trans-cinnamic acid, a deamination reaction. This reaction is considered an essential step in the phenylpropanoid pathway producing many products, including lignin, involved in plant defense reaction. The polyphenol oxidases are enzymes that often increase their activity in response to stress, and one of its main roles seems to be to promote the protection of the cell [60].

With hypotheses that silicon could to be an elicitor that potentiates the defense mechanisms of *Citrus reticulata* to CBF, Vieira et al. [61] used silicon in the form of potassium silicate (K_2SiO_3) to assess the activity of enzymes peroxidase, polyphenol oxidase, and phenylalanine ammonia-lyase. Results obtained by Vieira et al. [61] showed that silicon is not only involved in mechanical restraints against insect feeding but also with biochemical changes. In their study, they concluded that the peroxidase and polyphenol activities indicated strong induction of plant defense against CBF.

Using principal components analysis–PCA, it is possible to see a clear characterization of the different patterns of peroxidase, polyphenol oxidase, and PAL activity in response to time after infestation of citrus blackfly. In addition, an isolated activity in relation to peroxidase and polyphenol oxidase may be observed, but there was overlap of activities between polyphenol and peroxidase activity (**Figure 1**).

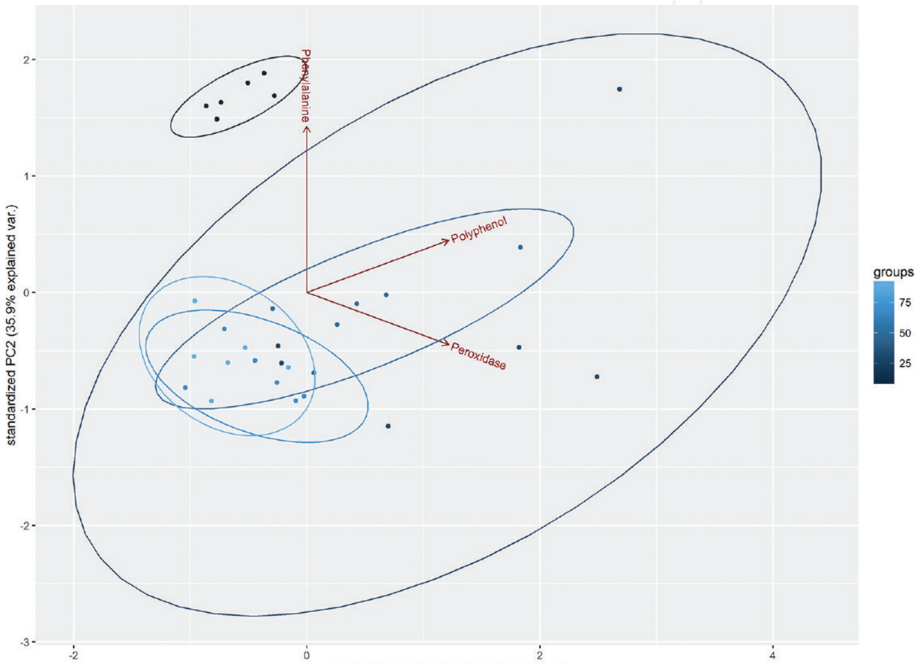

Figure 1. Biplot of enzymes activity mediated by silicon on seedlings of *Citrus reticulata*. The dots represent the mean activity, whereas the arrows represent the vector of each variable. Original data are showed in Fruits (2016) [61]. Copyrights (2016) with permission from EDP Sciences.

There is evidence that the increase in peroxidase and polyphenol oxidase activity revealed the induction of synthesis of compounds for plant defense against CBF, but this effect depended on the time of *A. woglumi* feeding and on the concentration of silicon. No effect of silicon as an activator of the PAL was observed [61].

Silicon probably triggers the natural defense mechanisms of plants such as the production of phenolic compounds, chitinases, peroxidases, and lignin, which can interfere with the physiology and development insect pests, and consequently silicon can reduce the oviposition preference and provide sublethal effects such as extending the development time and nymphal mortality [50]. A positive correlation between peroxidase activity and the development of *A. woglumi* was registered after use of silicon [61].

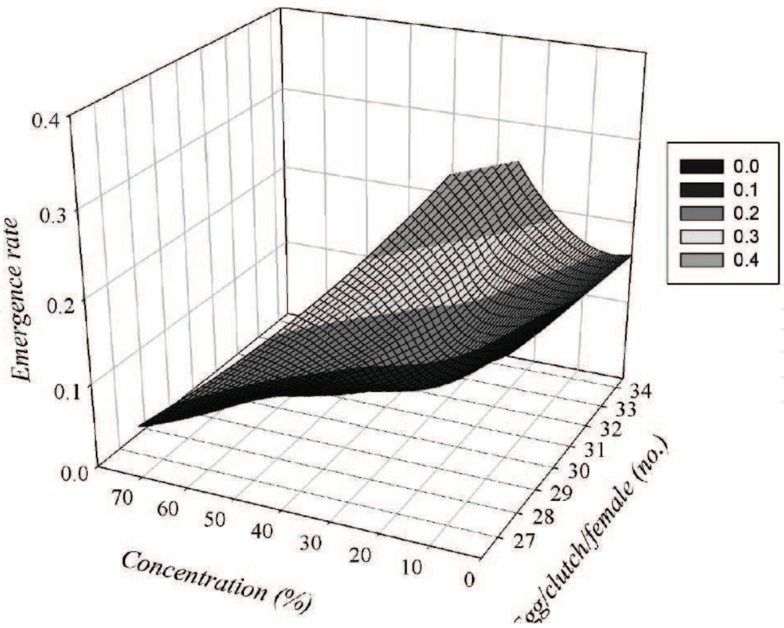

Figure 2. Effect of doses of potassium silicate on the average number of egg / clutch/ female and adult emergence rate of citrus blackfly. Original data are showed in [62]. The elicitor silicon may cause reduction in population growth rate of CBF, providing greater mortality, stimulating growth and plant development that is coenfirmed with the increase or the simple presence of defense substances, which are the peroxidase enzymes and polyphenol. Therefore, resistance induction is a promising alternative for the management of CBF, activating the synthesis of plant defense compounds.

Our results expressed in **Figure 2**, reveal that silicon doses promote low emergence rate. In the control treatment, an emergence rate was recorded as approximately 40%, significant reduction was observed with increasing of silicon doses with an emergence rate near to 5% in all doses used of silicon. But, it is clear that there is no great influence on eggs/clutch/female (**Figure 2**).

6. Final considerations

In Brazil, citrus is frequently affected by various pests. CBF has been causing severe damage, impacting the economy and reducing the citrus production. Mapping allows spatial visualization of the pest in the agroecosystem, allowing rational control with targeted applications, reduce production costs and decrease the negative impacts of pesticides, population fluctuation and spatial dependence of CBF in citrus, trapping as a representative sample of CBF is a tool to promote management of CBF, to decision making only when necessary. Conservative and release of natural enemies like Chrysopidae are potential to control CBF populations. Besides, to reduce populations of CBF ovicidal action based in some products such as oils from cotton seed, *E. globulus*, *A. sativum*, *R. communis* are valuable (please see **Table 1**). The use of silicata to induce citrus defense mechanisms with the increased activity of peroxidase and polyphenol oxidase presents a promising tool.

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