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CROP SCIENCE

The use of toxic baits for the suppression of Mediterranean fruit fly in mango orchards

CLÉBER ANTONIO BARONIO, RUBEN MACHOTA JUNIOR, MARCELO Z. NUNES, BEATRIZ A.J. PARANHOS, DANIEL BERNARDI, FLÁVIO ROBERTO M. GARCIA, & MARCOS BOTTON

Abstract: *Ceratitis capitata* (Wiedemann, 1824) is an insect of major economic importance in the mango orchards of the submedium of the São Francisco River Valley, the main area of mango production and exportation in Brazil. To provide alternatives for the management of *C. capitata*, toxic baits based on alpha-cypermethrin (Gelsura®) and spinosad (Success® 0.02 CB) were evaluated in three commercial mango experiments during two consecutive harvests: 2016/2017 (experiment 1 - area 1) and 2017/2018 (experiment 2 -area 2 and experiment 3 - area 3). According to the results, there was a large reduction in the infestation of *C. capitata* after five sequential applications of the alpha-cypermethrin (6 $g.ha^{-1}$) and spinosad (0.38 $g.ha^{-1}$) toxic baits performed at seven-day intervals during mango fruit ripening in all experiments and years (harvest) evaluated. Compared with the untreated plots, the plots with alpha-cypermethrin and spinosad applications showed a significant reduction in the damage induced (fallen fruits and/or on trees) by *C. capitata*. The management of *C. capitata* in mango orchards can include the use of the toxic bait based on alpha-cypermethrin, which represents an alternative to rotate with spinosad toxic bait in the São Francisco River Valley.

Key words: *Ceratitis capitata*, attract & kill, alpha-cypermethrin, spinosad, chemical control.

INTRODUCTION

The Mediterranean fruit fly (medfly) *Ceratitis capitata* (Wiedemann, 1824) (Diptera: Tephritidae) is considered a main insect pest species of mango in Brazil (Malacrida et al. 1998, McQuate & Liquido 2017). The São Francisco River Valley region, located in the states of Bahia and Pernambuco, is considered the main mango production center (Ferreira et al. 2010, Silva et al. 2014). Currently, the management of *C. capitata* adults and larvae has been carried out mainly with the use of organophosphate insecticides (Navarro-Llopis et al. 2013, Harter et al. 2015, Botton et al. 2016). Additionally, due to their broad spectrum and rapid action on fruit flies, organophosphate insecticides were once the most common insecticides in toxic bait formulations (Stark et al. 2004, Ruiz et al. 2008). However, the marketing of some of the major systemic organophosphorus insecticides has been banned, mainly because of concern for human health and the environment (Raga and Sato 2011, Morelli et al. 2012, Botton et al. 2016). Due to these aspects related to environmental management and damage, it is necessary to search for and develop new strategies for the management of fruit flies.

It is known that in Integrated Pest Management (IPM) in mango orchards, cultural practices such as orchard sanitation, and other tactics including 'attract & kill' and mass trapping has been successful in suppressing the *C. capitata* population in mango orchards (Morelli et al. 2012, Cook & Fraser 2015, Navarro-Llopis et al. 2015). However, it has been established that the use of toxic baits can be a useful tool in the management of *C. capitata* (Baronio et al. 2018), as verified for *Anastrepha fraterculus* (Weidemann, 1830) (Diptera: Tephritidae) (Harter et al. 2015), without the need for insecticide application (Navarro-Llopis et al. 2013).

These management strategies is used by producers and growers of São Francisco River Valley mango orchards, who usually spray the ready-to-use toxic bait Success® 0.02 CB (0.24 g. L^{-1} spinosad) (= GF-120® NF), as performed in other countries (Mangan & Moreno 2009). However, a new toxic bait formulation, Gelsura® (6.0 g.L^{-1} alpha-cypermethrin), is in the process of registration for the management of fruit flies in Brazil, with promising results for the management of fruit flies (Jang et al. 2005, Navarro-Llopis et al. 2011, Reynolds et al. 2016, Baronio et al. 2018, Vargas et al. 2018). Thus, the objective of this work was to evaluate the effectiveness of toxic baits based on alpha-cypermethrin and spinosad in the management of *C. capitata* on mango orchards.

MATERIALS AND METHODS

Three experiments were carried out on mango (*Mangifera indica* L.) orchards on three different farms, during two consecutive harvests: 2016/2017 and 2017/2018, located in the municipality of Casa Nova, BA (9°23’41”S; 40°44’55”W – Area 1), and the other two in Petrolina, PE (9°10’57”S; 40°31’07”W – Area 2 and 3), respectively. On each farm, we selected 6.0 ha of ‘Kent’ and ‘Tommy Atkins’ plants, with 5.0 m between plants and 7.0 to 8.0 m between rows. Previous studies have demonstrated that in the submedium of San Francisco River Valley, *C. capitata* infestations occur at high levels in mango orchards throughout the year.

Treatments

For *C. capitata* suppression in mango, the following two toxic bait formulations were used: Treatment 1 (T1): Gelsura® (alpha-cypermethrin) at 6.0 g.ha^{-1} - 3.0 L.ha^{-1} spray solution) (Basf SA, São Paulo, Brazil) and Treatment 2 (T2) Success® 0.02 CB (spinosad) at 0.38 g.ha^{-1} - spray solution) (Dow AgroSciences Industrial Ltda. São Paulo, Brazil). As a negative control (Treatment 3 - T3), an area was not treated with any insecticide to manage *C. capitata*. The Gelsura® toxic bait was prepared at a ratio of 1 part commercial product to 2 parts water (volume by volume, v/v) in a similar manner to the Success® 0.02 CB toxic bait (1:1.5).

Field Experiments

Three experiments in the field were evaluated during two consecutive harvests: 2016/2017 (Area 1 - experiment 1) and 2017/2018 (Area 2 - experiment 2 and Area 3 - experiment 3). The experiment (area) 1 (2016/2017) was carried out in 3.0 ha of a 10-year-old ‘Tommy Atkins’ mango tree orchard (330 plants per hectare) located in Petrolina, PE. The treatments evaluated were: T1 - Gelsura®, T2 - Success® 0.02 CB or T3 - control treatment without application. The toxic baits were applied after the first catch in the monitoring traps to ensure that *C. capitata* adults were in each plot and in five sequential applications at 7-day intervals following the methodology proposed by Baronio et al. (2018). The spray jets were applied to every plant spaced 33 m² from the previous plant and directed to the trunk bifurcation located approximately 1.5 m high to form a cluster of drops at a specific point. The Gelsura® toxic bait volume per jet was 10 mL (3.0 L.ha^{-1} of spray solution) and the Success® 0.02 CB toxic bait was 13.3 mL (4.0

L.ha^{-1} of spray solution), based on previous experiments, for a total of 300 points per hectare for both formulations. The experimental design was a randomized complete block design, with three treatments containing four replicates (0.25 ha) per treatments.

The experiment (area) 2 and experiment (area) 3 (2017/2018), were carried out in a 6.0 ha area (density of 300 plants per hectare) located in Petrolina, PE, in a 6-year-old 'Kent' mango orchard and 6.0 ha area (of 350 plants per hectare) located in the municipality of Casa Grande, BA, in an 8-year-old 'Tommy Atkins' mango orchard, respectively. The treatments evaluated were: T1 - Gelsura®, T2 - Success® 0.02 CB or T3 - control treatment without application for each area of study (experiment 2 and experiment 3). The experimental design was a randomized complete block design, with three treatments containing four replicates (0.5 ha per repetition) per treatments and area (experiment 2 and experiment 3).

Monitoring of *C. capitata* adults

In all treatments and repetitions, four Jackson traps were baited with the parapheromone trimedlure (Iscalure® TML-plug, Isca Tecnologias Ltda., Ijuí, RS, Brazil), following the methodology proposed by Baronio et al. (2018). The level of the C. capitata population determined every week from prematuration until the physiological maturation of the mangoes (Rodrigues et al. 2013). The number of C. capitata adults captured in the Jackson traps in the experimental areas was determined weekly after the application of toxic bait at 35, 28, 21, 14, 7 and 0 days before harvest (DBH), following the methodology proposed by Baronio et al. (2018) in grape orchards. Treatment traps were placed ≈5 m apart and hung from mango plants. All flies captured in monitoring traps were removed from traps weekly, emptied into individually identified paper bags and counted in the laboratory.

Evaluation to injuries in mango fruits

For evaluate the damage caused by *C. capitata* larvae and the oviposition spots (oviposition punctures) caused by *C. capitata* females in in the fruits, were collected tirty fallen fruits from in the two central rows of each repetition. Similarly, in each repetition we evaluated the occurrence of punctures in 30 previously marked fruits. The evaluation of the damage caused by *C. capitata* was performed at 14, 7 and 0 DBH as described by Baronio et al. (2018).

Statistical analysis

The data obtained from the weekly capture of adult male *C. capitata* in the different treatments were transformed into log complement to meet the normality assumptions, using the Shapiro-Wilk test, and homogeneity, using the Barlett test. Subsequently, the mean values were submitted to analysis of variance (ANOVA) using the F-test ($P \leq 0.05$) and, when statistically significant, the mean values were compared by the Tukey test ($P \leq 0.05$). The number of damaged mango fruits was subjected to a two-way analysis of variance with PROC GLM (SAS Institute 2011). The differences between the treatments within each harvest and year were determined by the least squares means (PDIFF option in PROC GLM) using Tukey's adjustment at 5% significance (SAS Institute 2011).

RESULTS

Monitoring of *C. capitata* adults

In 2016/2017 experiment – Area 1, compared with the control condition, the two toxic baits tested suppressed *C. capitata* adults (Fig. 1). At 35 DBH, a high number of adults were captured in all areas, showing the high population of the

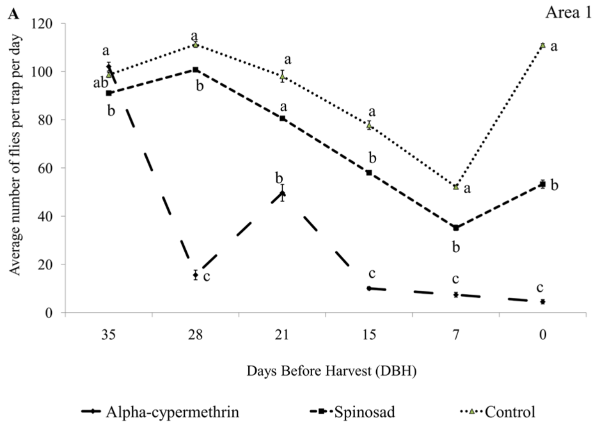

Figure 1. **Average number of flies per trap per day (average ± standard error) showing the *Ceratitis capitata* infestation reduction over six weeks of evaluations in mango crop areas during the period the 2016/2017 (experiment 1 (area 1)., Petrolina, PE, Brazil, 2017. The “days” lines followed by the same letter do not significantly differ as determined by the Tukey test (*P* > 0.05).**

insects in each area. The subsequent evaluations verified that there was a significant reduction in the number of insects captured in all three treatments; however, compared with the control, the Gelsura® and Success® 0.02 CB toxic baits reduced the number of medflies captured in all evaluations (F= 23.51; df = 2, 121; *P* < 0.0001). When comparing only the toxic bait formulations, the alpha-cypermethrin-based Gelsura® showed a greater reduction in the number of insects captured than the spinosad-based Success® 0.02 CB in all evaluations, reaching a 96% and 48% infestation reduction at harvest (0 DBH), respectively (Fig. 1).

The experiment (area) 2 (2017/2018 harvest), the plots where toxic baits were applied also showed suppressed *C. capitata* populations during the period from 35 DBH to 0 DBH; the Gelsura® and Success® 0.02 CB toxic baits reduced the infestation level below the infestation level of the control treatment (Fig. 2). In this area, there was no difference (F= 38.12; df= 2, 121; *P* < 0.5644) between the toxic baits with regard to the number of medfly adults captured, although the Gelsura® toxic bait provided an infestation reduction of 79% at 0 DBH, while the infestation reduction was only 64% for the Success® 0.02 CB toxic bait (Fig. 2). The experiment (area) 3 (2017/2018 harvest), all plots containing toxic bait applications suppressed the medfly population until 0 DBH (Fig. 3). The plots where the Gelsura® and Success® 0.02 CB toxic baits were applied had reduced *C. capitata* populations, with flies per trap per day (FTD) values of 5.28 and 10.0, respectively, and the *C. capitata* population in these plots were lower than that in the control plot, with 35.9 FTD at 0 DBH (F= 41.76; df= 2, 121; *P* < 0.0001) (Fig. 3).

Injuries in mango fruits

In 2016/2017 experiment – Area 1, there was a significant reduction in the cumulative damage of fallen mango fruits (F= 16.11; df= 2, 44; *P* < 0.0001) in the plots where the Gelsura® (60% fallen mango fruits) and Success® 0.02 CB toxic baits were sprayed (67% fallen mango fruits) compared with the control plot (98% fallen mango fruits) (Fig. 4). For damaged fruits, the

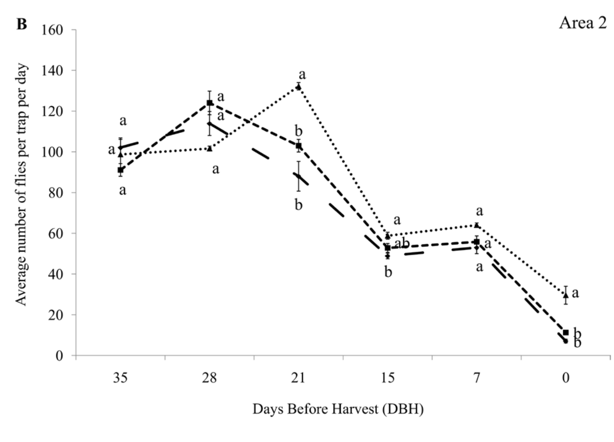

Figure 2. **Average number of flies per trap per day (average ± standard error) showing the *Ceratitis capitata* infestation reduction over six weeks of evaluations in mango crop areas, during the period the 2017/2018 (experiment 2 (area 2). Petrolina, PE, Brazil, 2018. The “days” lines followed by the same letter do not significantly differ as determined by the Tukey test (*P* > 0.05).**

damage to the fruits in the experimental plots sprayed with the Gelsura® toxic bait (0.7% of fruits were punctured) and Success® 0.02 CB (3% of fruits were punctured) toxic bait was significantly lower (F= 22.60; df= 2, 44; *P* < 0.0011) than the damage to the fruits in the control plot (13.0% of fruits were punctured). In the experiment (area) 2 (2017/2018), the highest amount of mango fruits recovered in the soil with punctures by *C. capitata* was observed in the control plot (28% fallen mango fruits), and the number of punctures observed was significantly higher (F= 15.11; df= 2, 44; *P* < 0.0001) in the control plot than in the plots treated with the toxic baits Gelsura® and Success® 0.02 CB (13% fallen mango fruits) (Fig. 4). In experiment 2, there were no punctures observed on the evaluated mangoes recovered from trees in all experimental plots. The experiment (area) 3 (2017/2018), the number fallen fruits observed in the plots treated with the Gelsura® (48% fallen mango fruits containing punctures) and Success® 0.02 CB toxic baits (52% fallen mango fruits) was statistically (F= 10.14; df= 2, 44; *P* < 0.0001) lower than that observed in the control plots (68% fallen mango fruits) (Fig. 4). Regarding the percentage of punctured fruits on trees, no significant difference was observed (F= 2.10; df= 2, 44; *P* = 0.1420) was observed among the Gelsura® toxic bait (0.0% of fruits punctured), Success® 0.02 CB toxic bait (0.33% of fruits punctured) and the control treatments (1.0% of fruits punctured).

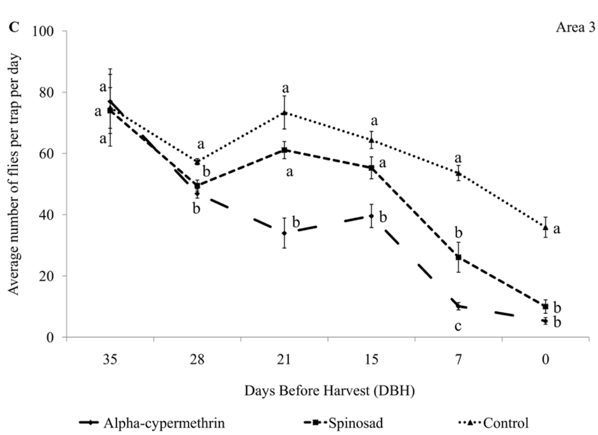

Figure 3. Average number of flies per trap per day (average ± standard error) showing the *Ceratitis capitata* infestation reduction over six weeks of evaluations in mango crop areas, during the period the 2017/2018 (experiment 3 (area 3)). Casa Grande, BA, Brazil, 2018. The "days" lines followed by the same letter do not significantly differ as determined by the Tukey test (*P* > 0.05).

DISCUSSION

The use of toxic baits started when *C. capitata* infestation was high on traps (between 74 and 102.7 FTD), approximately 70 days after flower anthesis or 40 DBH (Rodrigues et al. 2013). However, even in this physiological phase, there were large *C. capitata* individuals trapped on the traps (about 5 to 8 fruit flies), probably due the presence of a large amount of aborted fruits in response to the high temperature, which is characteristic of this region (Carvalho et al. 2004). It was also observed that although the toxic baits reduced the *C. capitata* population in all tested areas, the population was still above 1.0 FTD, which is the accepted level for export (Navarro-Llopis et al. 2013).

The high population during the initial development of fruits and the incapability of toxic baits to control 100% of the insects require special attention by growers and highlights the need for the adoption of complementary strategies to bring the fruit fly population below accepted levels, such as the collection and destruction of aborted fruits and starting toxic bait applications at least 40 days before harvest.

The use of toxic baits is an essential technique to suppress *C. capitata* adults as an alternative to spraying conventional insecticides (Navarro-Llopis et al. 2013, Baronio et al. 2018). The reduction in the adult population recorded in areas treated with a spray solutions of the toxic bait based on alpha-cypermethrin (3.0 $L.ha^{-1}$) was

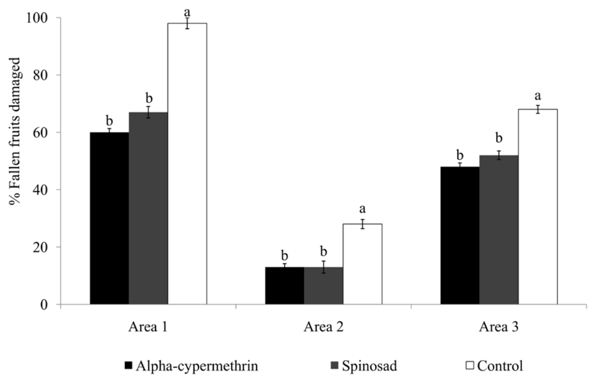

Figure 4. Percentage of mango fruit damage caused by *Ceratitis capitata* in each treated plot over three weeks of evaluations in mango crop areas, during the period 2016/2017 and 2017/2018. The "area 1, 2 or 3" columns followed by the same letter do not significantly differ as determined by the Tukey test (*P* > 0.05).

greater than those treated with the spinosad-based toxic bait (4.0 L,ha^{-1}). This finding is related to alpha-cypermethrin, which is a polymer matrix containing a series of food attractants (Ruiz et al. 2008), and the parapheromone trimedlure, which results in marked attraction and capture of *C. capitata* males. This bait consequently reduces the population in the traps baited with the parapheromone Iscalure® TML-plug, resulting in a more reduction in infestation than that observed with the Success® 0.02 CB toxic bait. Promising results were shown by a toxic bait based on alpha-cypermethrin in Europe for the suppression of *C. capitata* and *Bactrocera oleae* in *Clonorchis sinensis* and *Olea europea* crops, respectively (Ruiz et al. 2008) and for the control of *C. capitata* populations in grape crops in Brazil (Baronio et al. 2018).

In mango orchards, the use of five sequential applications of toxic bait based on alpha-cypermethrin at 7-days intervals starting 35 days prior to harvesting reduced the infestation of medfly adults to levels that were lower than or equal to the areas treated with the spinosad toxic bait and the untreated areas (control). One variable to be evaluated in future studies is the FTD index at higher intervals between applications, since both of these baits can last for a long period of time in the São Francisco River Valley, where precipitation is low, depending on the season (Lopes et al. 2017, Baronio et al. 2018).

In the São Francisco River Valley, fruit growers often use chemical management with insecticide sprays for the total area or toxic bait formulations. In this way, the ready-to-use toxic baits based on alpha-cypermethrin and spinosad can reduce *C. capitata* infestations and the percentage of damaged fruits. Both toxic baits can be used in an insecticide rotation with etofenprox (Safety®) because they are effective and authorized for pest management in mango crops (Morelli et al. 2012). However, due to restrictions on the use of chemical products by the consumer market demand for products without contaminants, the use of toxic baits such as spinosad and alpha-cypermethrin allows for the efficient management of *C. capitata* without contaminating mango fruits or the environment with insecticide residues (Vargas et al. 2013, Botton et al. 2016, Baronio et al. 2018).

Thus, the 'attract & kill' technology by using toxic baits containing alpha-cypermethrin is a management tool for the suppression of the *C. capitata* population in mango orchards and can be an alternative to the rotation of active ingredients such as spinosad, which is the only ready-to-use toxic bait registered for mango crops, in addition to etofenprox and acetamiprid, which are used as conventional insecticides for medfly in the São Francisco River Valley.

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CLÉBER ANTONIO BARONIO[1]
https://orcid.org/0000-0003-2040-8815

RUBEN MACHOTA JUNIOR[3]
http://orcid.org/0000-0003-2012-1726

MARCELO Z. NUNES[1]
https://orcid.org/0000-0003-2040-8815

BEATRIZ A.J. PARANHOS[2]
https://orcid.org/0000-0001-6814-3831

DANIEL BERNARDI[1]
https://orcid.org/0000-0003-4495-2575

FLÁVIO ROBERTO M. GARCIA[1]
https://orcid.org/0000-0003-0493-1788

MARCOS BOTTON[3]
https://orcid.org/0000-0002-0554-3157

[1]Universidade Federal de Pelotas, Programa de Pós-Graduação em Fitossanidade, Departamento de Fitossanidade, Faculdade de Agronomia Eliseu Maciel, 96010-970 Pelotas, RS, Brazil

[2]Embrapa Semiárido, Rodovia BR-428, Km 152, s/n, Zona Rural, 56302-970 Petrolina, PE, Brazil

[3]Embrapa Uva e Vinho, R. Livramento, 515, Caixa-postal 130, 95701-008 Bento Gonçalves, RS, Brazil

Correspondence to: **Daniel Bernardi**
E-mail: dbernardi2004@yahoo.com.br

Author contributions

CAB, RBJr, and MZN conducted the laboratorial and field experiments. CAB, MZN and DB wrote the manuscript. All authors read, contributed to revisions, and approved the manuscript.