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CROP SCIENCE

Sequential sampling plan for *Ceratitis capitata* (Diptera: Tephritidae) in guava orchards

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Abstract: This study aimed to elaborate a sequential sampling plan for *C. capitata* in commercial orchards of guava. 90 McPhail traps were randomly installed in three guava orchards in a transverse direction for 23 weeks. The data were submitted to sequential probability ratio test. Adopted the average of 0.3 *C. capitata* for the level of security and 0.7 for the control action. In this sequential sampling plan was defined the average number of 0.40 adults of *C. capitata* for each trap McPhail (sample). The sequential plan generated is unprecedented and will contribute to the rapid and safe decision making in the control of *C. capitata* population in guava farming.

Key words: Fruit farming, decision making, population monitoring, integrated pest management, Medfly.

INTRODUCTION

The fruit production offers economic development to Brazil, because approximately 90% of the production of fruits in the world are consumed in the producing countries themselves. The rest is exported *in natura* and in an industrialized way (Rodrigues 2008). In Brazil, the Gross Domestic Product (GDP) of the fruit production reaches two billion reais. Guava is a fruit native to South America, and one of the most consumed in all tropical regions. Brazil has its domestic production estimated at more than 7% of the total of guavas consumed throughout the world. Brazil produced a total of 578,608 tonnes of guavas in 2018, yielding R$ 578,608 million reais (Instituto Brasileiro de Geografia e Estatística 2018). The fruit has tannins and flavonoids, as well as antimicrobial and antioxidant activities (Iha et al. 2008). The cultivation of this guavas in Mato Grosso do Sul is mainly for domestic consumption (Nicácio et al. 2019). However, significantly contributes to the creation of jobs and generates income for the family farming. Encouraging the planting of guava can qualify the workforce and fix the man to the field (Petinari et al. 2008).

In addition to the need for adequate management for the production of guavas, relevant information on *Ceratitis capitata* (Wied 1824). Medfly is the main insect pest of fruits worldwide (Baronio et al. 2019) in particular in the Neotropical region. Therefore, there is a need to use suppression techniques of the Mediterranean fly (medfly) to minimize the injury to fruits. In addition to the direct damage to the premature fall of fruits, the ones that are drilled by the ovipositor of *C. capitata*, even if the eggs are unviable, to ripen submit marks of oviposition punctures and this cheapens the fruits commercially. Furthermore, the presence of medfly in orchards, leads to an increase in the use of pesticides, increasing production costs and decreasing the possibility of increased income for producers.

In Brazil, *C. capitata* has occurrence in agroecosystems in all regions. The method of monitoring done currently, employs the MAD index (number of adults captured/trap/day) to assess the level of infestation, which justifies the decision to control. The common sampling is the only currently used to medfly, however, sequential sampling allows a reduction in the cost and time of sampling (Zanetti 2000). There is a worldwide shortage of studies of sampling plans to tefritids. However, recently, was created the first sequential sampling plan for the fruit flies of the genus *Anastrepha* for orchards of guava (Nicácio et al. 2018) The objective of this work was to provide subsidies for the population monitoring of fruit flies in orchards, mainly of guava. The construction of a sequential sampling plan to flies of silkworms in commercial guava orchards.

MATERIALS AND METHODS

Characterization of sampling areas

The adults of *Ceratitis capitata* were captured in McPhail traps installed in three orchards of guava trees of cultivate new Millennium. Situated in the municipality of Ivinhema-MS: Santa Luzia farm, trees with four years of age (22° 17' 10'' S / 053° 56' 46" W), altitude of 420 m; São José farm (Site 1), with six years (22° 16' 18'' S / 053° 54' 58" W), altitude 397 m and at mettupalaiyam (Site 2) with three years (22º 15' 59" S and 53º 54' 01" W), altitude 409 m. The ratings occurred in the period from August 2013 to January 2014, totaling 23 weeks.

Ivinhema municipality is located to the south of the state of Mato Grosso do Sul, with semi-humid tropical climate, with dry winter and rainy summer. The climate is classified as humid mesothermal climate (rainy summers and dry winters), June and July being the period of lower temperatures below 18 °C, and January the hottest month, with temperatures above 22 °C (Köppen et al. 2007).

Monitoring

At each site were installed 30 McPhail traps, approximately 1.80m from ground level, attached to the branches of guava. The outline was systematized in the transverse direction and random in the longitudinal direction, after the area be flag from one to 12 and repeated 30 times. The attractive food used in traps McPhail was corn protein hydrolysate (5%), replaced weekly. The adults of *C. capitata* were deposited in containers with ethanol 92.8%.

Data analysis

The number of adults of *C. capitata* was established by setting threshold of negative binomial distribution (Bn) in 18 individuals. This value was used to describe the spatial distribution of the population of this species. To define the lines of decision-making that compose the spreadsheet of field sampling, were used the equations as Fernandes et al. (2003). Based on the method of Bn were used the averages of 0.3 and 0.7 in 30 traps in 30 traps to the line of the level of security and control to the equation of the line, respectively, with $\alpha = 0.02$ and $\beta = 0.20$.

The spreadsheet of field of sequential distribution plan was built for *C. capitata* using the model of Sequential Probability Ratio Test (SPRT) (Wald 1947). This test is based on the Operating Characteristic Curve {CO(p)} and the Curve of Expected Size of Sampling Units Ep(n) for any type of spatial distribution, aiming to test the hypotheses $H_0: \mu_0 = 0,3$ And $H_1: \mu_1 = 0,7$ With the smallest possible number of sample units. The reliability of adopting a decision right or wrong was represented by probability indicated in CO(p), which provides a perspective to finish the sampling and does not suggest the control to a level of infestation of medfly in culture of

guava. Now $E_p(n)$ represents the average number of observations needed to take the decision to perform or not the control. The two curves were used for the functions of (Young & Young 1998).

RESULTS

From the data provided by the equations of lines in the upper and lower levels, outlined the sequential sampling plan for the decision of the security level and the level of control against *C. capitata*. It was determined the level of security in S_0 = -2,5394 + 0,4644n, from the capture of 1.0 Adult (on average) of medfly by six McPhail traps, and the action level of control in S_1 = 4.5186 + 0,4644n with 5 adults of *C. capitata* caught in any one of the pitfalls of the orchard (Figure 1).

It was set in the field worksheet the sequential sampling for *C. capitata* in two lines (security level and action level of control). For the security level is estimated in an adult of *C. capitata* per trap and the level of control was established on the basis of five individuals of medfly, accumulated concomitantly in the set of traps installed in the orchard (Table I).

The characteristic curve of operation CO(p) represented on average 0.3 adults of medfly per trap, within a 1% probability of error in the acceptance of the security level. From the average of a adults of *C. capitata*, this error tends to zero. It was found that the curve CO(p) had a steep slope and the greater this slope, the greater will be the power to distinguish the two hypotheses (levels of security and action). It is known that test with a larger number of sample units (above 30 traps) lead by induction to results more robust and reliable up to a certain limit established by a statistical method, being unnecessary higher sampling effort (Figure 2).

The number of sample units expected $E_p(n)$ of the sequential test of probabilistic reason (Wald 1947) for the total population of *C. capitata*, suggests that with an average of 0.5 infestation with adults of *C. capitata* per sample, it will be necessary to use at most 17 McPhail traps in the area evaluated. For a set of seven traps, the average number of medfly adults will be of one individual (Figure 3). With an average equal to or greater than two adults of *C. capitata* in a particular area of orchard, you will need a sample size with two traps (Figure 3).

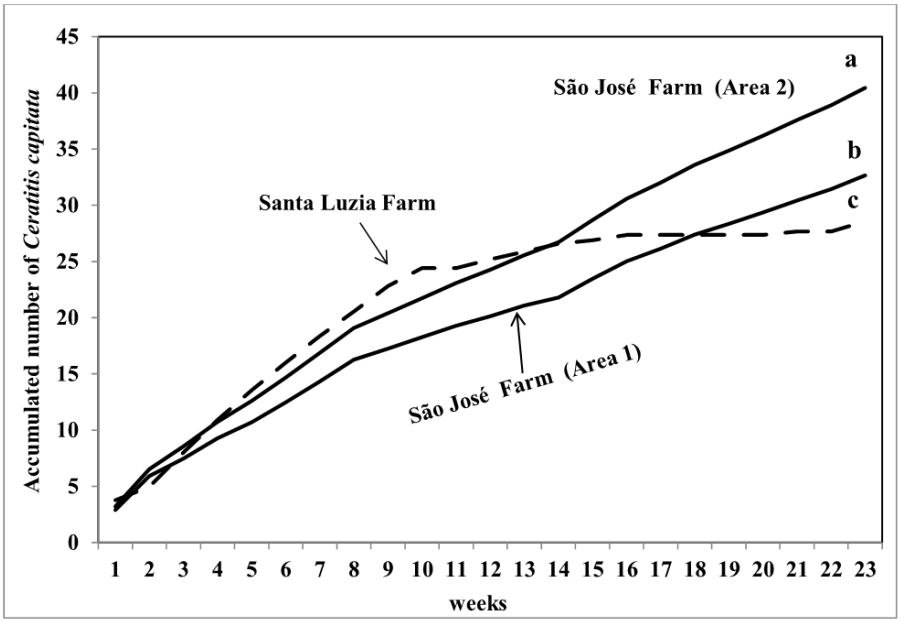

Figure 1. Lines of decision of the sequential sampling plan for the number of adults of *Ceratitis capitata* caught in McPhail traps with attractive food, following the theoretical pattern of the negative binomial (Nb), based on the Sequential Probability Ratio Test (SPRT) in orchards of guava (*Psidium guajava*) in the Ivinhema-MS, Brazil.

Table I. Adult populations of *Ceratitis capitata* (Diptera: Tephritidae) captured in McPhail traps in guava orchards, *Psidium guajava* (Myrtaceae), cultivar Novo Milenio: Aggregation indexes, distribution adjustment test and management type of Ivinhema municipality. Mato Grosso do Sul, Brazil.

NF♀♂	A.M	Aggregation Indexes				Frequency distribution						Type of management	
		FTD	I	I δ	K-factor	Poisson		NB		PB			
						χ^{2Signf}	g.l	χ^{2Signf}	g.l	χ^{2Signf}	g.l	Pg/Sp	lB/Mp
8	6	0.04	1.28^{AL}	4.29^{AL}	0.97^{AG}	2.15^{NS}	1	0.51	0^{i}	2.56	0^{i}	N/N	5/5
9	5	0.04	1.87^{AG}	5.83^{AL}	0.34^{AG}	6.84**	1	1.50	0^{i}	7.06	0^{i}	N/E	3/3
9	7	0.04	1.41^{AL}	2.50^{AL}	0.73^{AG}	0.10^{NS}	1	0.93	0^{i}	0.11	0^{i}	N/E	5/5
10	7	0.05	1.31^{AL}	2.00^{AL}	1.07^{AG}	3.56^{NS}	1	1.24	0^{i}	4.37	0^{i}	E/S	2/2
10	7	0.05	1.52^{AL}	3.00^{AL}	0.64^{AG}	1.09^{NS}	1	0.00	0^{i}	1.16	0^{i}	E/S	2/3
10	9	0.05	0.90^{AL}	0.67^{AL}	-3.22^{UN}	019^{NS}	1	0.01	0^{i}	0.17	0^{i}	N/E	5/5
10	7	0.05	1.52^{AL}	4.00^{AL}	0.64^{AG}	1.09^{NS}	1	0.00	0^{i}	1.16	0^{i}	N/N	5/5
11	9	0.05	1.03^{AL}	1.36^{AL}	11.70^{AL}	0.16^{NS}	1	0.10	0^{i}	0.19	0^{i}	N/N	2/3
12	10	0.06	0.97^{AL}	1.82^{AL}	-11.60^{UN}	0.01^{NS}	1	0.04	0^{i}	0.02	0^{i}	N/N	5/5
13	7	0.06	1.86^{AG}	3.27^{AL}	0.50^{AG}	5.81**	1	1.55	-1^{i}	6.01	0^{i}	N/N	4/4
16	11	0.08	1.52^{AL}	2.00^{AL}	1.03^{AG}	30.93**	1	0.31^{NS}	1	0.37	0^{i}	E/S	¼
16	7	0.08	2.29^{AG}	3.50A^{AG}	0.41^{AG}	8.78**	1	2.76^{NS}	4	28.40	0^{i}	S/N	½
17	12	0.08	1.18^{AL}	1.43^{AL}	3.17^{AG}	0.47^{NS}	1	0.08	0^{i}	0.54	0^{i}	N/N	5/5
18	12	0.09	1.79^{AG}	2.45^{AL}	0.76^{AG}	0.34^{NS}	1	1.52^{NS}	1	0.37	0^{i}	N/S	4/5
22	10	0.10	3.00^{AG}	3.83^{AL}	0.37^{AG}	31.48**	2	0.86^{NS}	2	6.45**	1	E/N	1/4
26	13	0.12	2.37^{AG}	2.58^{AL}	0.63^{AG}	36.26**	2	1.95^{NS}	2	14.92**	2	S/N	1/1
34	15	0.16	1.63^{AG}	1.55^{AL}	1.81^{AG}	10.07**	2	4.33^{NS}	2	13.94**	1	E/N	1/4
37	15	0.18	2.67^{AG}	2.34^{AL}	0.74^{AG}	34.77**	3	1.48^{NS}	3	13.33**	2	N/S	5/1
37	20	0.18	1.27^{AL}	1.24^{AL}	4.60^{AG}	4.67^{NS}	3	2.14^{NS}	2	0.46^{NS}	1	N/E	4/4
40	12	0.19	5.29^{AG}	4.19^{AG}	0.31^{AG}	21.98**	2	5.59^{NS}	3	34.20**	1	S/S	1/4
46	18	0.22	2.10^{AG}	1.84^{AL}	1.39^{AG}	9.21*	3	1.80^{NS}	1	12.89**	2	N/E	3/4
53	15	0.25	4.05^{AG}	2.70^{AL}	0.58^{AG}	27.64**	4	3.51^{NS}	3	30.27**	2	N/N	3/4
59	19	0.28	3.10^{AG}	2.05^{AG}	0.94^{AG}	11.50**	2	5.45^{NS}	2	21.69**	2	E/N	1/2
63	18	0.30	3.56^{AG}	2.20^{AG}	0.82^{AG}	30.73**	4	5.79^{NS}	5	32.38**	3	N/N	5/1
70	19	0.33	3.50^{AG}	2.05^{AL}	0.93^{AG}	45.91**	4	11.40^{NS}	6	52.72**	3	S/N	1/4
77	18	0.37	5.88^{AG}	2.86^{AG}	0.53^{AG}	54.40**	4	2.88^{NS}	4	62.49**	3	E/N	1/2
82	17	0.39	6.76^{AG}	3.06^{AG}	0.47^{AG}	77.05**	4	1.93^{NS}	5	126.61**	3	E/N	2/2
149	24	0.71	9.24^{AG}	2.61^{AG}	0.60^{AG}	50.67**	6	9.35^{NS}	8	47.33**	5	N/N	1/4
184	24	0.88	21.18^{AG}	4.20^{AG}	0.30^{AG}	181.68**	4	16.10*	6	260.2**	3	N/S	1/4
241	28	1.15	15.71^{AG}	2.78^{AG}	0.55^{AG}	210.45**	5	17.03*	8	196.21**	3	N/N	3/4
275	23	1.31	22.29^{AG}	3.25^{AG}	0.43^{AG}	73.17**	3	10.67^{NS}	8	109.15	1	E/N	2/3
450	29	2.14	28.91^{AG}	2.80^{AG}	0.54^{AG}	331.85**	2	16.95^{NS}	12	311.01	0^{i}	E/N	2/3
764	29	3.64	42.76^{AG}	2.59^{AG}	0.61^{AG}	224.76**	4	21.36*	10	43.46	-1^{i}	E/N	1/3
784	27	3.73	23.94^{AG}	1.85^{AG}	1.14^{AG}	285.03**	3	68.86**	11	153.94	0^{i}	N/N	5/1
1035	25	4.93	93.70^{AG}	3.60^{AL}	0.37^{AG}	197.59**	6	24.97^{NS}	8	35.37	-1^{i}	N/N	5/1
1117	30	5.32	40.67^{AG}	2.04^{AG}	0.94^{AG}	266.97**	6	12.68^{NS}	12	21.95**	2	E/N	1/2
5811	27	27.67	178.13^{AG}	1.88^{AG}	1.09^{AG}	206.81**	1	15.02*	6	0^{i}	0^{i}	N/N	5/2

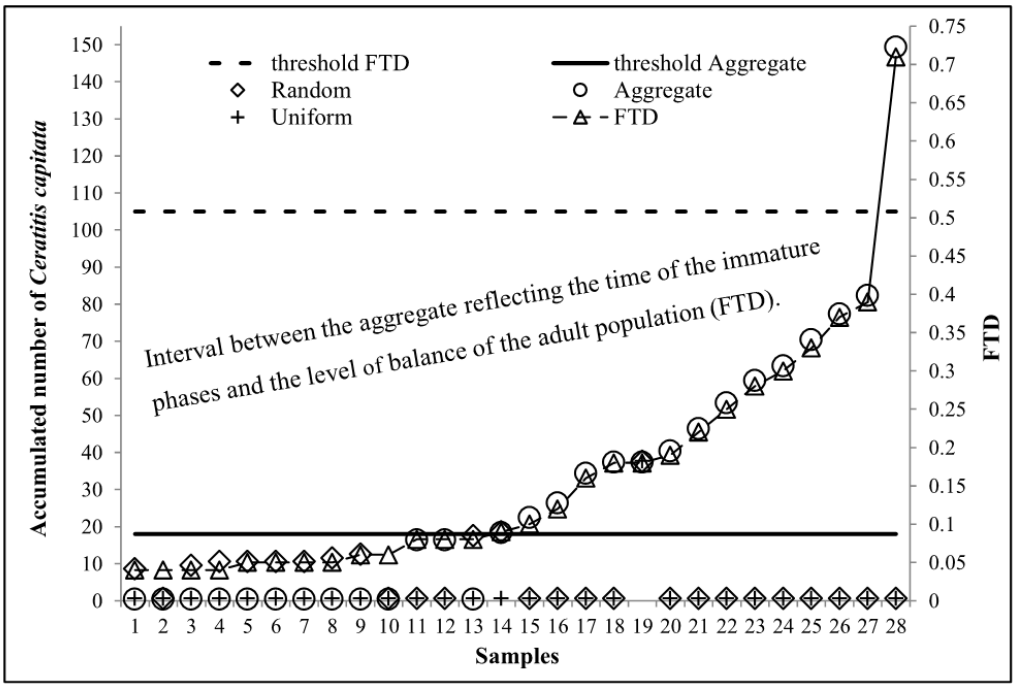

Figure 2. Operating Characteristic Curve CO(p) of the Sequential Probability Ratio Test (SPRT) for the population of *Ceratitis capitata* in guava 'New Millennium' in three orchards in the municipality of the Ivinhema, Mato Grosso do Sul, Brazil.

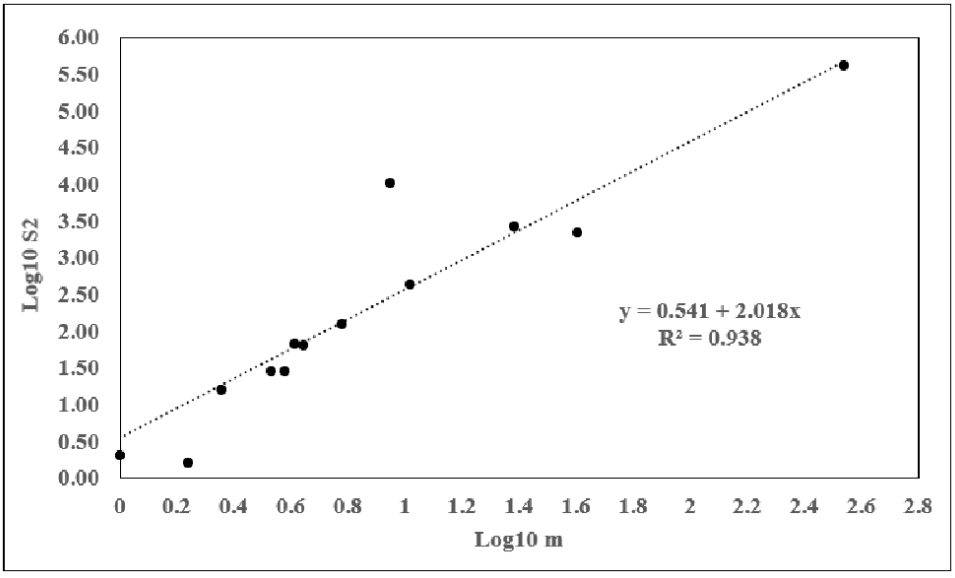

Figure 3. Curve of Expected Size of Sampling Units Ep(n) by the Sequential Probability Ratio Test (SPRT) for the population of *Ceratitis capitata* in three orchards of guava 'New Millennium', municipality of the Ivinhema, Mato Grosso do Sul, Brazil.

DISCUSSION

The cumulative number of adults of *C. capitata* varies from 0.4644 (beta) for each increase of one sampling unit (one McPhail trap). The lower the initial number of limit the level of control, the greater will be the biotic potential of the target pest species. In guava orchards, it was found that *C. capitata* presents higher biotic potential that the co-occurring species of the genus *Anastrepha* (Nicácio et al. 2018). The sequential sampling plan for the medfly population monitoring provided by the equations of lines, is intended to be used in a program of integrated pest management (IPM) as a tool for decision-making. The model adjusted by negative binomial (Bn) has the predictive power of estimating the number of adults, and indirectly reflects the potential damage of the

juvenile phase in the orchard (Table I). Because the potential of loss is associated with the level of the presence of the larval stage.

The assumptions for the proper use of this spreadsheet in a sequential sampling plan for *C. capitata* in guava orchards, are: employ at least one trap McPhail by orchard of ½ hectare area and this should stay installed in the orchard(es) for more than three consecutive days (Table I). Traditionally, the recommended number of McPhail traps per unit of area (ha) is a trap per hectare, above 50 ha is recommended the employment of a trap for each 10 ha (Nascimento et al. 2000).

In the field, the technician should add up the number of adults captured in medfly in the first sampling unit (McPhail trap) with the second trap, and so on. This action should be repeated until the values are equal or superior to that of the column that represent the two levels (upper and lower), referring to the last trap used. Therefore, if the total number of adults of *C. capitata* counted is equal to or exceeding the control action level (upper limit); it is recommended an action for population suppression of medfly. If the values do not exceed the upper limit established in the spreadsheet and, if it remains between the upper and lower levels, it is recommended to continue the evaluation of the set of traps. However, when the number of adults is below the level of security, you can wait for a maximum period of two weeks, to repeat the sampling of adults of *C. capitata* in orchard.

The reliability of the sampling plan tested by operating characteristic curve CO(p), indicated that when it gets on average 0.3 adults of *C. capitata* per trap McPhail, there will be a 1% probability of error in recommending the control. In fact, the control of medfly is still not necessary until 0.69 adults of *C. capitata* in the sample (set of McPhail traps). From the average of 1.5 adults of *C. capitata* captured in McPhail traps in orchards of guava, the probability of incurring in error type I(H_0), does not recommend the control when this is necessary (H_1) is virtually zero (Figure 2).

The ideal number of McPhail traps in orchards of guava trees to detect the occurrence of adults of *C. capitata* is inversely proportional to the size of its population (Figure 3).

The hypotheses tested (H_0: $\mu_0=0,3$ and H_1: $\mu_1=0,7$) by this sampling plan using the spreadsheet for the decision against *C. capitata* in culture of guava anticipates any surprise of lack of information about the presence of these species in orchards. May support the producers in the employment of the medfly control techniques. This technique is facilitated by the aggregate distribution behavior of medfly. His constant monitoring in the orchard prevents the risk of pest infestation of this species in other commercial fruit trees cultivated or not. In addition to facilitate the monitoring of *C. capitata* and *Anastrepha*, since it uses the same source of resources for the maintenance of their progeny.

It was found that the required number of McPhail traps for the practice of sequential sampling of *C. capitata* in orchards of guava is a few traps by orchard, providing low cost in comparison to the expenses with other inputs (biocides, cultural abuse, among others), if the population is not detected in advance in the orchard. With low average of adults per sample (set of traps) it is possible to take a decision on the levels of infestation of this pest species (Figure 3).

CONCLUSION

It is drawn up for the first time a sequential sampling plan for *Ceratitis capitata* in guava orchards with a spreadsheet for use by producers/technicians who will serve as a framework for decision-making on the levels of security and control of *C. capitata* in guava orchards.

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REFERENCES

BARONIO CA, SCHUTZE, IX, NUNES MZ, BERNARDI D, MACHOTA R, BORTOLI LC, ARIOLI CJ, GARCIA FRM & BOTTON M. 2019. Toxicities and residual effect of spinosad and alpha-cypermethrin-based baits to replace malathion for *Ceratitis capitata* (Diptera: Tephritidae) control. J Econ Entomol 112: 1798-1804.

FERNANDES MG, BUSOLI AC & BARBOSA JC. 2003. Amostragem sequencial de *Alabama argillacea* (Hubner) (Lepidoptera: Noctuidae) em algodoeiro. Neot Entomol 32: 117-122.

IHA SM, MIGLIATO KF, VELLOSA JCR, SACRAMENTO LVS, PIETRO RCLR, ISAAC VLB, BRUNETTI IL, CORRÊA MA & SALGADO HRN. 2008. Estudo fitoquímico de goiaba (*Psidium guajava* L.) com potencial antioxidante para o desenvolvimento de formulação fitocosmética. Rev Bras Farmacogn 18: 387-393.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2018. Produção Agrícola. Disponível em https://cidades.ibge.gov.br/brasil/pesquisa/15/0. Acesso em 16/03/2020.

KÖPPEN W, GEIGER R, PEEL MC, FINLAYSON BL & MCMAHON TA. 2007. Update world map of the Koppen-Geiger climate classification. Hydrol Earth Syst SC 11: 1633-1644.

NASCIMENTO AS, CARVALHO RS & MALAVASI A. 2000. Monitoramento populacional. In: MALAVASI A AND ZUCCHI RA (Eds), Moscas-das-frutas de importância econômica no Brasil: conhecimento básico e aplicado. Ribeirão Preto: Editora Holos, Brazil, p. 109-112.

NICÁCIO J, OLIVEIRA I, UCHOA MA, FACCENDA O, ABOT AR, FERNANDES MG & GARCIA FRM. 2018. Sequential sampling plan for fruit fly species of the Genus *Anastrepha* (Diptera: Tephritidae) in guava orchards. An Acad Bras Cienc 90: 3607-3614.

NICÁCIO J, OLIVEIRA I, UCHOA MA, FACCENDA O, ABOT AR, FERNANDES MG & GARCIA FRM. 2019. Spatial distribution and control levels of *Anastrepha* spp. (Diptera: Tephritidae) in guava orchards. An Acad Bras Cienc 91: 1-13.

PETINARI RA, TERESO MJA & BERGAMASCO SMPP. 2008. A importância da fruticultura para os agricultores familiares da região de Jales-SP. Rev Bras Frutic 30: 356-360.

RODRIGUES ET. 2008. Recomendações para o cultivo de frutas tropicais no Estado de Mato Grosso do Sul. Dourados: Editora UEMS, 122 p.

WALD A. 1947. Sequencial analysis. J Wiley & Sons, Inc. N. York, 212 p.

YOUNG LJ & YOUNG JH. 1998. Statistical ecology: a population perspective. Boston, Kluwer Academic Publishers, 565 p.

ZANETTI R. 2000. Amostragem de populações de insetos no manejo de pragas. Editora UFLA, 30 p.

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All conceived and planned the experiments. JLS, JN and MPO carried out the experiments. All authors contributed to the interpretation of the results. ARA, FRMG and JN took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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