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Original Article

Spatial distribution of *Ceratitis capitata* in guava orchards and influences from orchard management

Distribuição espacial de *Ceratitis capitata* em pomares de goiabeira e influências do manejo de pomares

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Abstract

The objectives of this research were: (i) to Estimate the quantitative occurrence of *Ceratitis capitata* captured in McPhail traps in cultivating guava; (ii) to investigate the spatial distribution patterns of *C. capitata* in guava orchards; (iii) to compare the index of the FTD (fruit fly/trap/day) to the type of spatial distribution of *C. capitata* with the Negative Binomial to set the best time for control of the population in the context of Integrated Pest Management; (iv) Verify the influence of the pruning, spraying, and mowing on the distributions of medfly in guava. Was used 30 McPhail traps installed in three commercial orchards of guava. The spatial distribution was evaluated by the regression model with the Taylor power method, from the log of variance to the log of the mean number of individuals. *Ceratitis capitata* has aggregated distribution behavior. The potential risk of economic damage is associated with aggregate distribution behavior. The beginning of this distribution indicates the most appropriate time for using control techniques.

Keywords: medfly, aggregated distribution, populational monitoring, captures, management.

Resumo

Os objetivos desta pesquisa foram: (i) estimar a ocorrência quantitativa de *Ceratitis capitata* capturada em armadilhas McPhail no pomares de goiabeira; (ii) investigar os padrões de distribuição espacial de *C. capitata* em pomares de goiabeira; (iii) comparar o índice do MAD (mosca da fruta/armadilha/dia) ao tipo de distribuição espacial de *C. capitata* com o Binomial Negativo para definir o melhor momento para controle da população no contexto do Manejo Integrado de Pragas; (iv) Verificar a influência da poda, pulverização e roçada nas distribuições da espécie em goiabeira. Foram utilizadas 30 armadilhas McPhail instaladas em três pomares comerciais de goiabeira. A distribuição espacial foi avaliada pelo modelo de regressão com o método Taylor power, do log da variância ao log do número médio de indivíduos. *C. capitata* tem comportamento de distribuição agregado. O risco potencial de dano econômico está associado ao comportamento da distribuição agregada. O início desta distribuição indica o momento mais adequado para o uso de técnicas de controle.

Palavras-chave: mosca do mediterrâneo, distribuição agregada, monitoramento populacional, capturas, manejo.

1. Introduction

There are 29 species of fruit flies of economic importance in the Americas belonging to the genera *Anastrepha* (12), *Rhagoletis* (10), *Bactrocera* (5), *Ceratitis* (1), and *Zeugodacus* (1) (Garcia et al., 2020). *Ceratitis capitata* (Wiedemann, 1824) (Diptera: Tephritidae) is the only species of the genus in the Americas (Garcia et al., 2020). To correctly manage their populations in agroecosystems, it is necessary to monitor and know the appropriate techniques for their population suppression since it is one of the main problems of fruit-growing in the country (Jean-Baptiste et al., 2021). Brazil is the third-largest fruit producer globally, surpassed by China and India. Due to its strategic location in the neotropical region, the country is one of the most important producers of tropical fruits and temperate climate, harvesting more than 7% of guavas and mangoes consumed globally (Comex do Brasil, 2016).

Research on spatial distribution using the numerical frequency measures the population by the theoretical frequency distribution model provides information on the biotic potential and the populations of the adult

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and juvenile phases. Thus, the study on the population distribution pattern better clarifies to the producer the valid population index 3 in which economic damage to production begins, adding confidence to monitoring and enabling the producer to make decisions for population suppression. There are few published papers on the spatial distribution of fruit flies (Deus et al., 2016; Garcia et al., 2017; Nicácio et al., 2019; Duarte et al., 2021; Araújo et al., 2022). This information is relevant because the economic damage risk potential of *Anastrepha* spp. was associated with the aggregate distribution behavior in guava orchards in Brazil (Nicácio et al., 2019).

Therefore, the objectives of this work are: (i) to estimate the quantitative occurrence of *C. capitata* captured in McPhail traps in cultivating guava; (ii) to investigate the spatial distribution patterns of *C. capitata* in guava orchards; (iii) to compare index the FTD to the type of spatial distribution of *C. capitata* with the Negative Binomial to set the best time for control of the population in the context of Integrated Pest Management; (iv) Verify the influence of the pruning, spraying and mowing on the population of *C. capitata* in guava.

2. Material and Methods

Ceratitis capitata was captured in McPhail traps arranged in three locations in the municipality of Ivinhema in the Novo Milênio guava cultivar. At the Santa Luzia site, with four-year-old guava (22° 17' 10" S / 053° 56' 46" W), altitude of 420 m; "Sitio San José "(site 1) growing at six years of age (22° 16' 18" S / 053° 54' 58" W), Altitude 397 m and the site San José (site 2) cultivar with three years of age (22 15' 59" S and 53 54' 01" W), altitude 409 m. samples were collected from august 2013 to January 2014, corresponding to 23 weeks.

Ivinhema is located south of the State of Mato Grosso do Sul, with a semi-humid tropical climate. The region, according to Köppen, is classified as a humid mesothermal climate, with rainy, hot summers and dry winters), with June and July being lower temperatures (less than 18°C) and January being the hottest month (greater than 22°C) (Peel et al., 2007). It presents itself as tropical altitude in some areas, presenting dry winter and rainy summer. Due to the longitudinal position of South America, the atmospheric dynamics of the region are linked to the action of the intertropical and extra-positive action centers with their high negative and subtropical pressures, represented by the Amazon and Chaco depressions.

McPhail traps were installed in the guava plants at about 1,80 m from the soil level, at number 30 in each site, distributed systematically in the transversal and random direction in the longitudinal direction (after the area was squared from one to 12 and repeated 30 times). The food attraction employed in the traps was corn hydrolyzed protein (5%), replaced every weekly. Flies were preserved in 92,8% alcohol and identified in the Laboratory of Taxonomy and systematics of Tephritidae, Universidade Federal de Grande Dourados, Dourados, MS, by Dr. Manoel Araécio Uchôa-Fernandes.

The type of spatial arrangement of individuals in the population of C. capitata (Diptera: Tephritidae), captured in McPhail traps, was determined by dispersion indices (mean-variance ratio, Morisita index, and negative binomial K parameter) with randomness removal by the chi-square test (Poole, 1974; Pielou, 1977; Southwood, 1978). Also, the field frequency data were adjusted to the theoretical frequency distributions (negative binomial distribution, positive binomial distribution, and Poisson distribution) using the adhesion chi-square test ($\chi 2$) (n=1440) (Young and Young, 1998). Another compared index was FTD = N/AXD, N = number of adults of *C. capitata* captured, A = number of traps evaluated, D = interval in days between collections. The FTD was defined in 105 flies for 30 traps in seven uninterrupted days of exposure. Taylor's power law (Taylor, 1961) describes the relationship variance (S^2) and mean ($\overline{x}$) through an exponential function (Equation 1):

$$S^2 = a\overline{x}^{\beta} \tag{1}$$

Where: α and β are the parameters. This relationship can be described according to the linear Equation 2:

$$\log S^2 = \log a + b \log \overline{x} \tag{2}$$

Where S^2 is the variance of the population, $\overline{x}$ it is the average of the population, a it is the intersection of variance and b is the slope of the regression line, which is an index that indicates the type of distribution of C. capitata. When b = 1 indicates random dispersion model; $b > 1$ indicates aggregate dispersion model; and when $b < 1$ indicates uniform dispersion model. The size of the fly population group is given by the intersection (a) with the Variance axis. This parameter refers to the average number of individuals captured in the same sample unit (trap), which is called the basic index of contagion of individuals. When, $\alpha = 0$, the basic component is the individual; $\alpha < 0$, indicates a separation between individuals and $\alpha > 0$ suggests that the basic element is the population of flies. To verify that the parameter β was significantly different from 1 and $a \neq 0$ the Student's "t" test ($p < 0,05$).

The Likert scale was applied to leaf biomass (LB) and mowing (Ro) variables, according to their percentage degrees of occurrence: 1 = 1/5 or from 1 to 20% of the total leaves for LB and Ro; 2 = 2/5 or 21 to 40% for LB and Ro; 3 = 3/5 or 41 to 60% for BF and Ro; 4 = 4/5 or 61 to 80% for BF and Ro e; 5 = 5/5 or 81 to 100% for BF and Ro.

The sites evaluated used conventional techniques to manage guava production (application of insecticides, pruning, mowing, and fertilization). To compare the types of management, the sample units were standardized and homogenized with the same number of repetitions for each treatment. The assumption of aggregate distribution adherence to *C. capitata* defined the threshold from 18 individuals in the same design.

The number of *C. capitata* was used to compare the types of management. The treatments did not adhere to the presuppositions of homogeneity and normality. Therefore, the Kruskal-Wallis test was used to verify whether there was an effect between treatments and the multiple comparisons by the Dunn-Bonferroni bilateral test ($\alpha < 0.05$).

The Monte Carlos method with Markov Chain (MCMC) was used to calculate the probabilities with the transition matrix. Therefore, the results were statistically analyzed using Bayesian statistical methods to corroborate the evaluation of the degree of uncertainty of the propositions. These methods followed the R models Kinas and Andrade (2010) indicated.

Taylor's Power Law (Taylor, 1961) was another model employed to evaluate the spatial distribution of C. capitata, compared with the result obtained by the model of frequency theoretical distribution. Taylor's Power Law describes the relationship between variance (S^2) and means (x¯) through an exponential function: S^2=αx¯^β where: α e β. t

This relationship can be described according to the linear equation: logS^2=loga+b logx¯, where S^2 is the population's variance, x¯ is the population's average, a is the intersection of variance, and b is the coefficient of the slope of the regression line. This slope is the index that indicates the type of distribution of *C. capitata* in the population that emerged from the colonization of host fruits. If b = 1 indicates random dispersion model; b > 1 indicates aggregate dispersion model; and b < 1 indicates uniform dispersion model. The size of the fruit fly's population group is given by the intersection (a) with the variance axis. This parameter refers to the average number of individuals captured in the same sample unit (i.e., the same trap), which is called the basic rate of contagion of the individual. When $\alpha = 0$, the basic component is the individual; $\alpha < 0$ indicates the separation between individuals, and $\alpha > 0$ suggests that the basic element is the fruit fly population. Student's "t" test ($p < 0,05$) with N-2 degrees of freedom was used to verify that the parameter β was significantly different from 1 and $a \neq 0$.

3. Results

The fluctuation of the accumulated number of adults of *C. capitata* in the orchard of guava Novo Milênio in the São José site (Site 2) was significantly higher in the orchard of the Santa Luzia site and the São José site (Site 1). The samples compared between the two orchards (sites 1 and 2) of the São José site were initially treated the same until the 11th week, when the treatment was interrupted. Still, the population of *C. capitata* remained in growth, but with emphasis on Site 2 (Figure 1).

In 1.110 sample units (McPhail traps) totaling 11,617 adults of *C. capitata* (Table 1) found that the number of 18 individuals was the threshold for their aggregation behavior. The number of flies in the samples that built the equilibrium level (range 1), control level (range 2) and economic damage level (range 3) bounded by the threshold lines (Table 1) were significantly different Kruskal-Wallis: ($p < 0.000$; $\chi 2= 31.85$; gl. 2; n = 37), of the intervals: 1 < 2 < 3, compared to the number of *C. capitata* by Dunn-Bonferroni's bilateral test ($p< 0.05$).

The average variance dispersion index I (Table 1) and the negative binomial distribution adherence test (Table 1) presented concordant results in 85% of the cases. Only three samples below the threshold of 18 adults indicated aggregate behavior. For samples above this threshold, this agreement was 100%. However, the random distribution behavior was 71.43% below the threshold (Table 1, column 7). The Bn dispersion index factor K was the most reliable, followed by the mean-variance ratio I. The Index of Morisita did not represent a safe model for determining the pest status of *C. capitata* in guava orchards, standing below the FTD threshold. This index was defined at 105 *C. capitata* for 30 traps on seven days of exposure (Table 1). The Bn K-factor dispersion and average variance indexes were more accurate with the FTD at the aggregate distribution threshold. As the number of flies captured increased, the k factor and the average variance were significantly representative of aggregation (Table 1).

Thirty-seven samples of the adults of *C. capitata* assessing distribution types and FTD index in 28 samples were sufficient to determine the thresholds established by the negative binomial (Bn) and the FTD index. They are thresholds for decision-making of the level of safety and control action for this pest species. The first 14 were below 18 individuals, representing more than 70% adherence to random distribution (Poisson) (Figure 2). Aggregate distribution and FTD index were significantly above the

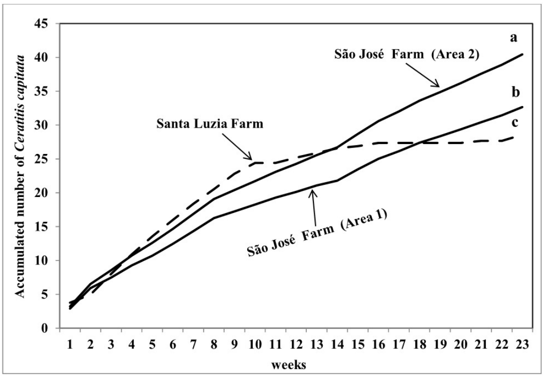

Figure 1. Population fluctuation of adults of *Ceratitis capitata* captured in McPhail traps in three guava orchards, Ivinhema, MS, Brazil.

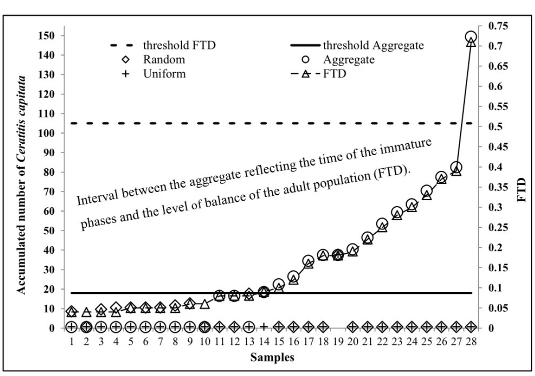

Figure 2. Number of fruit fly/trap/day (FTD) of *Ceratitis capitata* and range of negative binomial thresholds (Bn) with other distributions, establishing the levels of safety and control activities for the Mediterranean fly in three guava orchards, Ivinhema, MS, Brazil.

Table 1. 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

Caption: ^{NS}Not significant adhering to the type of distribution; **1% error probability (p<0.01); *5% error probability (p<0.05); g.l = Degree of freedom of the $\chi 2$ distribution; Signf = chi-square value and significance; ^{i}Degree of freedom and calculated chi-square, being insufficient to adhere to the type of distribution; A.M = NA = Number of traps with *C. capitata* capture (Positive); NF = Number of flies (n = 3150); FTD index = Ratio of the number of flies per trap and the number of days of exposure of these traps; I = Average Variance Ratio Index; Iδ = Morisite Index; K = k-exponent calculated by the method of moments, with the value of $\chi 2$, corresponding to an error probability of 5% (α = 0.05), with the significance of the occurrence of the number of *C. capitata* for the indices: AG = aggregate distribution ; UN = Uniform distribution; AL = Random distribution; Poisson = "Random" frequency distribution; NB = Negative Binomial Frequency Distribution "aggregated or contagious" and PB = Positive Binomial Frequency Distribution "Uniform". Pg = Pruned guava trees; Sp = Orchard sprayed; LB = Leaf biomass cover in; Mp = Weeds cut (mowing); S = type of management performed; N = type of management not performed; E = Period in which the cultivar was under the effect of the management implemented and; '- - -' = Decision-making thresholds at the security and control action levels.

threshold of 18 adults from sample 14 with 100% adherence to these methods. In the following 14 samples, the FTD index exceeded the established Bn threshold. In the 19th sample, the frequency of captured adults joined simultaneously to the three distributions (Figure 2). The FTD index was above the recommendation of the level of action for controlling C. capitata defined by the Bn, which should guide decision-making with population reduction measures for the Mediterranean fly in guava orchards (Figure 2).

The equation: Y = -0.67 8.72 $\bar{x}$, of Taylor's power regression, of the log of variance of the number of adults of *C. capitata* by the log of the mean, of this population in the guava orchards, was adjusted by ANOVA, (F = 10.51; g.l = 22; (p < 0.01) (Taylor, 1961), with the coefficient of determination adjusted by 30%. It joined the aggregate distribution, since β the regression parameter value was significantly higher than the unit ($b > 1$) compared by the Student t test (t = 3.24; p < 0.01). The size of the group of fly's populations given by the parameter a that is the intersection in the Variance axis, referring to the average number of individuals captured in the same sample unit (trap), was characterized by $\alpha = 0$, defining *C. capitata* as a basic element of visitation to resource source *t* (p < 0.01).

The populations of *C. capitata* in the guava orchards, cultivar Novo Milenio, presented a significant difference between the management techniques routinely adopted by fruit growers: Radical pruning spraying (simultaneous) about pruning alone. It was found that spraying with insecticides reduced the average number of adults of *C. capitata* in the guava orchards (Table 2). When spraying occurred, the average number of adults of *C. capitata* was equivalent to that of the two management techniques together compared from 1 to 3 spraying. A high population level occurred in the lack of management of pruning and spraying. Only pruning did not influence the population of *C. capitata*.

Effect among orchards (Kruskal-Wallis: χ^2= 6.76; gl. 2; n = 69; p<0.001). Multiple comparisons were FTD using the Dunn-Bonferroni bilateral test (p< 0.001), in which equal letters did not differ significantly.

Pruning contributed 36% of the occurrence of medfly, while spraying presented a contribution of 0.17%. Plants with lower leaf biomass follow the second-lowest occurrence of medfly with 17.92%. The management of weed mowing shows the most minor influence on the occurrence of medflies (45.91%). Therefore, all these treatments evaluated when used influence the reduction of the presence of these flies, with emphasis on the spraying and decline of plant leaf biomass (Table 3).

Therefore, the plausible sequence in the contribution in the probability of the presence of medfly in guava orchard is preferred to establish presence in a relative frequency distribution of occurrence over the defined time intervals for these treatments, with the following probability of 0.0017 for PV; 17.92% for leaf biomass, 36% for PD and 45.91% for weed mowing. The contribution of spraying to reducing the presence of medflies concerning mowing is 92% (Table 3).

Regarding the risk of occurrence of flies in these treatments or management, it is observed that the lower chance of occurrence of medfly is associated with spraying and the lower effect is for mowing, which usually presents opportunities of occurrence higher than the other managements in 3.1050 times of the cases. The others have a lower risk of occurrence, with a probability of this risk of occurrence occurring at 93% in PD, in LB, it is 2.5250 times, and with PV, it is 44.47% (Table 2).

Taylor's power parameter b was significant by adhering to the aggregate distribution form for the adult phase of almost all species of *Anastrepha* that has the guava as the primary host. The species of *Anastrepha*, considered pests, only adhered to the aggregation index at random in a low number of individuals. However, over 20 individuals of flies of the species obtained adhered to the aggregate form (Table 3).

The number of adults of Ceratitis captured in McPhail traps, compared with the age (years) of the new millennium guava cultivar, was evaluated by the Kruskal-Wallis method: $\chi 2$= 13.73; gl.=2; n = 180; p<0.001. This significance occurred only between the 4-year-old (location = JL) and 6-year-old (location = JS2) age group compared to the 3-year-old group (location = JS3). This evidences that the plant age variable of the samples in JS1 and JS2 does not influence the adult population index. Probably this difference between these and the JS3 became significant, due to the influence of the types of management as observed in the analysis of the results in Table 2.

The equation adjusted by Taylor's method for each species of *C. capitata* it was: Y = a + BX. The Taylor's Power regression model, from the log of variance by the

Table 2. Comparison of the population distribution of adults of *Ceratitis capitata* (Diptera: Tephritidae) captured with McPhail traps in guava orchards, *Psidium guajava*, (Myrtaceae), cultivar Novo Milenio, submitted to different types of management (Ivinhema-MS, Aug municipality).

Type of management	Distribution of *Ceratitis capitata*					Multiple comparison
	Minimum Number (#)	Maximum	Median	Average	SD	
Pruning and Spray	0	18	0.24	0.41	1.29	a
Spraying	0	30	0.34	0.85	2.53	a
Pruning	0	170	0.50	3.84	14.15	b
No pruning and no spraying	0	623	1.32	25.90	77.29	c

SD = mean standard error.

Table 3. Probability of occurrences of *Ceratitis capitata* in guava orchards, *Psidium guajava*, 'Novo Milenio', in the transition matrix model with the use of the Markov Chain Monte Carlo (MCMC) method (Bayesian). Data obtained in the city of Ivinhema, Mato Grosso do Sul, Brazil.

Treatment	Management		$p(\theta\|y)$			
	Pg/Sp	**Lb/Mp**	**Pg**	**Sp**	**Lb**	**Mp**
t1	E/N	1/4	0.038	0	0.050	0.251
t2	E/N	1/3	0.043	0	0.061	0.220
t3	E/N	1/2	0.052	0	0.072	0.176
t4	E/N	1/2	0.052	0	0.072	0.176
t5	E/N	2/3	0.038	0	0.104	0.189
t6	E/N	2/2	0.043	0	0.119	0.145
t7	E/S	1/4	0.033	0.008	0.047	0.220
t8	E/S	2/3	0.033	0.008	0.090	0.167
t9	E/S	2/2	0.038	0.008	0.104	0.128
t10	N/E	3/4	0	0.013	0.119	0.194
t11	N/E	3/3	0	0.015	0.137	0.167
t12	N/E	5/5	0	0.010	0.151	0.185
t13	N/E	4/4	0	0.012	0.144	0.176
t14	N/N	1/4	0	0	0.072	0.352
t15	N/N	2/3	0	0	0.144	0.264
t16	N/N	3/4	0	0	0.155	0.251
t17	N/N	5/5	0	0	0.180	0.220
t18	N/N	4/4	0	0	0.180	0.220
t19	N/N	5/2	0	0	0.256	0.128
t20	N/N	5/1	0	0	0.299	0.075
t21	N/N	5/1	0	0	0.299	0.075
t22	N/S	1/4	0	0.010	0.061	0.295
t23	N/S	4/5	0	0.006	0.144	0.220
t24	N/S	5/1	0	0.008	0.256	0.062
t25	S/N	1/4	0.022	0	0.061	0.295
t26	S/N	1/2	0.033	0	0.090	0.220
t27	S/N	1/1	0.043	0	0.119	0.145
t28	S/S	1/4	0.018	0.008	0.050	0.251
Probability	-	-	**0.3600**	**0.0017**	**0.1792**	**0.4591**
Chance of occurrences	-	-	**0.9300**	**0.4475**	**2.5250**	**3.1050**

log of mean for the *C. capitata* species cited, i.e. b > 1, is significant by ANOVA ($F = 304{,}05$; $p < 0{,}001$; g.l = 20) where the which means that for each unit increased in the mean log, an increase in the log of the variance of b has been observed, confirming aggregate distribution for these species, and the adjusted determination coefficient, $R^2 > 0.938$ explaining the total variation of this behavior. The value of the aggregation index (*b*) was significantly higher than 1 by the student's *t* (5,17; p < 0,001) for the hypothesis *Alpha* (h0: a = 1 *vs* h1 a ≠ 1, where: Alpha (a < 0, a = 0 e a >0) and.; *t* (17,44; p < 0,001) for the hypothesis Beta (h0: b = 1 vs h1: b ≠ 1), where: Beta (b < 1, b = 1 e b > 1). The intercept value log_{10}^{a} was -a, significantly lower than zero (t; p < 0,001), indicating the occurrence of distance between individuals of the C. capitata population at the time of evaluation. The aggregation indexes (a,b) were highly significant. Both evaluated by Student's t-test for B0 = a>0, (t = 5.17; p < 0.001), inferring an aggregation behavior for this population of flies. For B1 = b>1, (t = 17.44; p < 0.001), meaning that for each unit increased in the log of the mean, there is an increase in the log of variance of 2.018 individuals of C. capitata, giving these flies have aggregated distribution behavior. Therefore, the use of analysis methods of Negative Binomial distribution and Taylor power conferred on C. capitata aggregated distribution behavior (Figure 3).

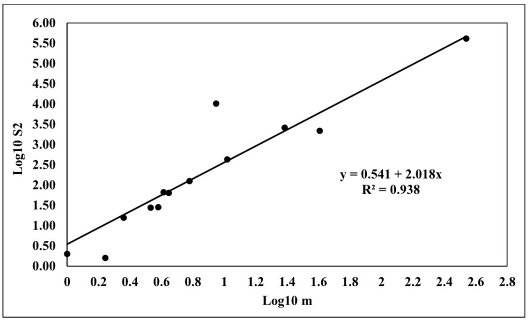

Figure 3. Estimates of the parameters of the regression analysis by the Taylor power model, adjusted by the F test to evaluate the spatial distribution and the t-test to compare the hypotheses of the aggregation index of Ceratitis capitata in guava orchards, Ivinhema-MS. Tests: ANOVA ($F = 304.05$; $p < 0.001$; g.l = 20); t (5.17; $p < 0.001$) for the Alpha hypothesis (h0: a = 1 vs h1 a ≠ 1, where: Alpha (a < 0, a = 0 and a >0) and; t (17.44 ; $p < 0.001$) for the Beta hypothesis (h0: b = 1 vs h1: b ≠ 1), where: Beta (b < 1, b = 1 and b > 1).

4. Discussion

The difference in the population dynamics of *C. capitata* between the orchards of the cultivar Novo Milenio in Santa Luiza and São José (Local 2) may be associated with the influence of the types of management. There was pruning and continuous spraying in the orchard of the Santa Luzia site. In contrast, in the São José site (site 2), this management was sporadic, mainly at the beginning of the collections until the 11th week (Figure 1), and later, this management was suspended.

In the first site, although it had near the orchard of guava, a coffee crop, which is the primary host of the Mediterranean fly, mango is also the host of this pest, the population of flies after pruning spraying decreased. This decrease could infer that it was caused by spraying; however, it may have occurred due to insecticide resistance at sites 1 and 2 of the São José site. There was spraying with insecticides; however, there was no decrease in the population. The resistance of *C. capitata* to insecticides were confirmed by Magaña et al. (2007). They used a *C. capitata* strain called W 4 km-malathion-resistant deformation, which had achieved resistance of about 180 times to malathion and proved that it developed cross-resistance of up to 16 times to trichlorfon, diazinon, phospmete and methyl chlorpyrifos. It also developed resistance to carbaril and lambda-cyhalothrin. Another population, called W-4 km, was submitted to selection pressure with lambdacialothrin and had a resistance of 35 times.

The significant difference in the number of adults of *C. capitata* between the threshold ranges of aggregate, distribution, and FTD indicates the reliability of these inferences in these ranges (Table 1). It was observed that it was not enough to validate the separation of randomness with few samples. It can be inferred that the dispersion indexes K factor of the Bn and the mean-variance ratio (I) are reliable for decision-making of the control of *C. capitata* in guava orchards and were higher than the FTD index at the aggregate distribution threshold. Therefore, the measure that increased the number of adults captured of C. capitata, k factor, and mean-variance ratio were significantly representative of aggregation (Table 1). The theoretical frequency distribution of the Bn was the one that best validated the aggregate distribution for *C. capitata* in orchards. The number of adults in the sample to adhere to this distribution pattern (Bn) is 18 individuals, standardizing the number of traps since the start of monitoring (Table 1).

The frequency distribution of fruit flies is ecologically described by a negative binomial distribution (Deus et al., 2016; Nicácio et al., 2019; Araújo et al., 2022). One, which is characterized by more significant than average variance, was observed in our results. This research demonstrated the importance of using the frequency distribution method for *C. capitata*, aiming at its monitoring in guava orchards to prevent this pest species from reaching the level of economic damage. This technique can be equated to any evaluation test that needs to be satisfied by data's normality, homogeneity, and collinearity. This is because at the beginning of the occurrence of aggregate distribution, the maximum number of adults of *C. capitata* from which it will be necessary to recommend control measures is defined here by the negative binomial in at least 18 adults of *C. capitata* per sample.

On the other hand, population monitoring using the FTD index to make a control decision would be recommended only after capturing 105 adults of *C. capitata* per sample. (Table 1). It is important to point out that, using the FTD index of 105 adults, the pest would already be installed entirely in the orchards, with significant economic losses. The reliability of the Bn is based on the fact that it is a sum of individuals not being influenced by the number of traps or their exposure days. The Bn allows you to define the capacity of the damage potential of *C. capitata* about FTD. Comparing both monitoring methods (Bn and FTD), there is a difference of about 301% efficiency in favor of Bn.

In Brazil, to determine the moment to control fruit flies, the most used tool is FTD (Nascimento et al., 2000); for this fly, in general, is considered a safe method with the indication of 0,5 flies (day traps)-1, using the Jackson trap. The determination of the number of adult fruit flies from which control action needs to be adopted is, in practice, dependent on the components: Input cost, cultural treatment, and the market value of the final product (fruits). On the other hand, if the level of control is affected by one of these components and action is not performed, this site will propagate these pests to neighboring properties, increasing their populations to the next harvest. Fruit flies can also disperse to other fruit trees that may become reservoirs of this pest group.

This study observed that the Bn model would prevent 16.300 adults of *C. capitata* from continuing in orchards in the next generation. Considering the total number of adults caught in traps (n= 11.617) and the sex ratio of *C. capitata* is 1:1, it would result in 5.808 females. On average, each female oviposits 550 eggs, with a viability of 80%; 16% of the larvae will reach the pupa phase, and about 4% will become adults. In the laboratory, the viability percentage was 70% for larvae, 60% for pupa, and 17% for adults of *C. capitata* (Zanardi et al., 2011). In comparing the aggregate distribution with the FTD index, it was verified that it had 646 adults of *C. capitata* were the most in the balance interval (security level) (Table 1). Between the action thresholds for the two methods, there was a 300% difference from FTD to Bn (Table 1).

The FTD index underestimates the potential for damage of *C. capitata* in orchards. Furthermore, the FTD favors the population increase of the Mediterranean fly, and, as a result, there is a greater possibility of this colonizing other host, which can serve as reservoirs. Inadequate management that favors this situation may result in the resurgence of the pest and its secondary population explosion and may cause resistance and tolerance to biocides used in the next generations against *C. capitata* (Table 1). The effect of spraying interferes with the population of *C. capitata* up to four weeks after applying these active measures. The permanence of invasive plants among the guava plants maintained the average population of *C. capitata*, and this FTD and management were difficult (Table 1).

Aggregate distribution (Bn) defined the threshold of 18 adults of *C. capitata* as a recommendation to initiate control decision-making (action level). This distribution indicates *C. capitata* potential as a pest associated with its dispersion behavior. This lower threshold leads *C capitata* to have a biotic potential higher than that of *Anastrepha* species and, therefore, its population reaches the status of pest more rapidly in orchards. The population was growing exponentially, meaning that it had already reached the level of economic damage (Figure 2).

The average number of 0.4 individuals of *C. capitata* per sample sets the security level (balance level = NE). Above 0.4 and below 0.7 means that sampling should continue. When the FTD indicated to continue sampling, Bn recommended control. The control action must be carried out on 18 adults of C. capitata that corresponding to the level above 0.7.

The decision-making efficiency through the proposed Bn is associated with the fact that the samples reflect the increase of individuals, indirectly representing the potential of the pest still in the egg, larvae, prepupa, and pupa phases (Figure 2).

The regression adjusted by Taylor ($logS^2 = -0.67 + 8.72\, log\overline{x}$) power method of the logarithm of variance of the number of adults of *C. capitata* as a function of the logarithm of the mean had the coefficient *b* > 1, a significant result using the Student's t test (t = 3.24; p < 0.05). This confirms the aggregate pattern of distribution of the Mediterranean fly. This value of 8.72 represents the slope of the adjusted straight and predicts that for each unit the most in the log of the mean there has been an increase of 8.72 units in the log of variance, with the variance explaining 70% of this dispersion behavior of *C. capitata*. This fly because it is exotic probably suffers greater influences from the environment in relation to *Anastrepha* spp. The value of the intercept was -0.67 not differentiating from zero (t = 3.24; p *C. capitata* is individual, being the = 0.21 individual evaluated by the equation

Even with the behavior being aggregated, it was equal to zero, therefore indicating that this fly has visitation in the resource source probably individually, by cospecific or interspecific repulsion with *Anastrepha* spp. In addition, it was more sensitive and took longer time to restore the population index. It presented higher population growth before spraying management activities. The *b* also shows a significant temporal growth rate of *C. capitata* population, probably due to the biotic potential ($log\, a_{10}$. $log\, a_{10}$).

When the peculiarities of the Taylor power model and the negative binomial are observed concerning the characterization of the behavior of the distribution type of this species, Taylor describes the relationship between the population variance log with prediction by the fixed Alpha and Beta parameters. This model also generalizes this behavior for samples of the temporal effect. Bn follows these effects for each sample. So, Taylor's power is spot-on efficient. The use of this method may interfere with the decision to make or not applications or other management activity, since it is generalizing the spatial behavior of these flies at that time, since the sample may reflect only the management effect and not the biological conditions of the insect and the environment.

The effects of the management techniques and the pattern of behavior of *C. capitata* were evidenced in the homogeneity in the central and dispersion measures that highlighted the efficiency of the Bn model. This reflects that the number of sample units in this experiment was adequate for numerical frequency calculations, accepting the aggregate pattern for 95% of the population of *C. capitata* (Table 2).

Taylor's Power Regression can also be used to evaluate the spatial distribution of fruit flies. However, it's application has limitations Only recommended when a general view is chosen, without interest in the effect of seasonality or temporality. The fact that the species have aggregate behavior in the adult phase is a consequence of the earlier stages (egg, larva and pupa) not being susceptible to control conditions and biotic and abiotic conditions. This is justified because these phases are endophytic (Table 3). This aggregation behavior of *C. capitata* favors its life cycle and indicates how much these flies have adequate biotic potential to achieve pest status. Another fact observed with the use of Taylor's Power Regression Model is that in the group of species of *Anastrepha* some may be pest for a certain species of fruit, not being considered a key pest for another fruit (Table 3).

The estimates of Taylor's Law parameters for counting the number of individuals of fruit fly species can also be used, because it had the F test significant for the number of adults of species important for guava orchard. And Taylor's Power parameter b compared by the t test, being significant for b > 1 adhering to the form of aggregate distribution in the adult phase for almost all species that have the guava as the primary host. This is because the adult stage is in aggregate distribution, favoring its mating behavior and possible because the adult stage is in aggregate distribution, favoring its mating behavior and possible dominance over

21 the food resource mainly in relation to other flies of *Ceratitis* (Tephritidae), both endophytic. The < 0 parting reinforces the condition of separation between the individuals of the population of *C. capitata*. possibly due to the behavior of oviposition marking and diversity of

hosts, besides abiotic factors, conditioning to a decrease in intraspecific competition.

5. Conclusions

1. The populations of *C. capitata* in the evaluated guava orchards of the cultivar Novo Milenio were considered high;
2. The distribution of *C. capitata* populations adhered to the negative binomial model;
3. The number of flies caught by traps/days (FTD) index underestimates *the C. capitata* populations in the field;
4. The negative binomial model (Bn) was the best method to evaluate the spatial distribution and the potential for economic damage of *C. capitata* in guava orchards, allowing to establish the moment of control action;
5. The radical pruning of guava trees of the cultivar Novo Milenio together with the spraying of insecticides or only the spraying influenced the reduction of the average number of adults of *C. capitata* in orchards and;
6. The Taylor potential method can momentarily assess the distribution of C. capitata in a Novo Milenio guava orchard.

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