**UNIVERSIDADE FEDERAL DE VIÇOSA**

**DAIANE DAS GRAÇAS DO CARMO**

# CONVENTIONAL SAMPLING PLAN FOR GREEN PEACH APHID, ***Myzus persicae*** (SULZER) (HEMIPTERA: APHIDIDAE), IN BELL PEPPER CROPS

**VIÇOSA - MINAS GERAIS**
**2021**

**DAIANE DAS GRAÇAS DO CARMO**

# CONVENTIONAL SAMPLING PLAN FOR GREEN PEACH APHID, *Myzus persicae* (SULZER) (HEMIPTERA: APHIDIDAE), IN BELL PEPPER CROPS

Dissertation presented to the Universidade Federal de Viçosa, as part of the requirements of Entomology Graduate Program to obtain the title of *Magister Scientiae*.

Advisor: Marcelo Coutinho Picanço

**VIÇOSA - MINAS GERAIS**
**2021**

**Ficha catalográfica elaborada pela Biblioteca Central da Universidade Federal de Viçosa - Campus Viçosa**

T

C287c
2021

Carmo, Daiane das Graças do, 1995-

Conventional sampling plan for green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), in bell pepper crops / Daiane das Graças do Carmo. – Viçosa, MG, 2021.

27 f. : il. ; 29 cm.

Texto em inglês.

Orientador: Marcelo Coutinho Picanço.

Dissertação (mestrado) - Universidade Federal de Viçosa.

Referências bibliográficas: f. 24-27.

1. Afídeo - Controle. 2. Amostragem. 3. Tomada de decisão. I. Universidade Federal de Viçosa. Departamento de Entomologia. Programa de Pós-Graduação em Entomologia. II. Título.

CDD 22. ed. 595.754

**DAIANE DAS GRAÇAS DO CARMO**

# CONVENTIONAL SAMPLING PLAN FOR GREEN PEACH APHID, *Myzus persicae* (SULZER) (HEMIPTERA: APHIDIDAE), IN BELL PEPPER CROPS

Dissertation presented to the Universidade Federal de Viçosa, as part of the requirements of Entomology Graduate Program to obtain the title of *Magister Scientiae*.

APPROVED: February 23, 2021.

Assent:

Daiane das Graças do Carmo
Author

Marcelo Coutinho Picanço
Advisor

## ACKNOWLEDGMENTS

Agradeço, primeiramente, a Deus por ter abençoado meus caminhos e ter me permitido tornar meu sonho possível.

A Universidade Federal de Viçosa e ao Programa de Pós-Graduação em Entomologia, pela oportunidade de realização deste curso.

Ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), a Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) - Código de Financiamento 001 e a FAPEMIG pelo financiamento dos meus estudos.

Ao professor Marcelo Coutinho Picanço pela participação na minha formação, orientação e amizade ao longo desses anos de convívio. A sua esposa Kátia e aos seus filhos Mayara, Luíza e Marcelo Filho, pelo agradável convívio.

Aos membros da banca, pela cordialidade em aceitar o convite e pela forma valiosa como participaram.

Aos amigos do Laboratório de Manejo Integrado de Pragas pelo convívio, troca de conhecimentos e especialmente pela grande ajuda neste trabalho.

As minhas amigas Ana Maria, Carolina e Jéssica, pelo apoio, incentivo e por todos momentos felizes compartilhados.

Ao Geovane, pelo amor, companheirismo, amizade, incentivo e paciência demostrada ao longo de nossa convivência.

Ao meu irmão Danilo, pelos conselhos, amizade e suporte.

Aos meus avós, Vicente e Maria, pelo incentivo e carinho.

Em especial, agradeço aos meus pais Divino e Maria das Graças, pelo amor incondicional, ensinamentos e dedicação desde o meu primeiro dia de vida.

Muito obrigada!

# BIOGRAPHY

DAIANE DAS GRAÇAS DO CARMO, filha de Divino do Carmo e Maria das Graças Reis do Carmo, nasceu em Viçosa, Minas Gerais, no dia 18 de janeiro de 1995.

Em março de 2014, ingressou no curso de Agronomia pela Universidade Federal de Viçosa, graduando-se em janeiro de 2019. Durante a graduação, de maio de 2014 a fevereiro de 2019 foi estagiária bolsista no Laboratório de Manejo Integrado de Pragas do Departamento de Entomologia da Universidade Federal de Viçosa, sob orientação do Professor Marcelo Coutinho Picanço. Em março de 2019 ingressou no curso de mestrado do Programa de Pós-Graduação em Entomologia/UFV.

## ABSTRACT

CARMO, Daine das Graças do, M.Sc., Universidade Federal de Viçosa, February, 2021. **Conventional sampling plan for green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), in bell pepper crops**. Advisor: Marcelo Coutinho Picanço.

The green peach aphid *Myzus persicae* is one of the most important pests in bell pepper crops. Conventional sampling plans are the starting point for the generation of pest control decision-making systems. However, sampling plans have not yet been determined for this pest in bell pepper crops. Thus, the objective of this work was to determine conventional sampling plans feasible for *M. persicae* in bell pepper crops in the vegetative and reproductive stages. The adequate sample for the evaluation of *M. persicae* populations in bell pepper plants in the vegetative stage was the 5$^{th}$ most apical leaf. For plants in the reproductive stage, the adequate sample for the evaluation of *M. persicae* populations was the 3$^{rd}$ most apical leaf. The beating of the apical part of the plants in a white plastic tray was the best technique for sampling *M. persicae* in bell pepper fields. *M. persicae* densities adjusted to negative binomial distribution and had a common aggregation parameter (Kcommom = 0.1816). The sampling plan consisted of 158 samples per field. This sampling plan was carried out in 42 min, 57 min and 1 h: 08 min in plots of 1, 5 and 10 hectares respectively. The cost of the sampling plan was US$ 1.19, US$ 1.59 and US$ 1.90 for plots of 1, 5 and 10 ha, respectively. The sampling plan developed in this study can be incorporated into integrated pest management programs, as it allows for an adequate assessment of *M. persicae* populations in bell pepper cultivations. The sampling plan is low cost (up to US$ 1.90 per sample), fast (up to 1 h: 08 min) and feasible.



Keywords: Aphids. Sampling unit. Decision-making systems. Control.

# RESUMO

CARMO, Daine das Graças do, M.Sc., Universidade Federal de Viçosa, fevereiro de 2021. **Plano de amostragem convencional para o pulgão verde, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), em cultivos de pimentão**. Orientador: Marcelo Coutinho Picanço.

O pulgão verde *Myzus persicae* é uma das pragas mais importantes na cultura do pimentão. Planos de amostragem convencionais são o ponto de partida para a geração de sistemas de tomada de decisão de controle de pragas. No entanto, ainda não foram determinados planos de amostragem para esta praga na cultura do pimentão. Assim, o objetivo deste trabalho foi determinar planos de amostragem convencional praticáveis para *M. persicae* em lavouras de pimentão nos estágios vegetativo e reprodutivo. A amostra adequada para avaliação das populações de *M. persicae* em pimentão em estádio vegetativo foi a 5ª folha mais apical. Para plantas em fase reprodutiva, a amostra adequada para avaliação das populações de *M. persicae* foi a 3ª folha mais apical. A batida da parte apical das plantas em bandeja plástica foi a melhor técnica para amostragem de *M. persicae* nos campos de pimentão. As densidades do pulgão verde se ajustaram a distribuição binomial negativa e tinham um parâmetro de agregação comum ($K_{commom}$ = 0.1816). O plano de amostragem consistiu em 158 amostras por campo. Este plano de amostragem foi realizado em 42 min, 57 min e 1 h: 08 min em parcelas de 1, 5 e 10 hectares respectivamente. O custo do plano de amostragem foi de US $ 1,19, US $ 1,59 e US $ 1,90 para parcelas de 1, 5 e 10 ha, respectivamente. O plano de amostragem desenvolvido neste estudo pode ser incorporado a programas de manejo integrado de pragas, pois permite uma avaliação adequada das populações de *M. persicae* em cultivos de pimentão. O plano de amostragem é de baixo custo (até US $ 1,90 por amostra), rápido (até 1 h: 08 min) e praticável.

Palavras-chave: Pulgões. Unidade de amostragem. Sistemas de tomada de decisão. Controle.

## SUMMARY

# 1. INTRODUCTION

Bell pepper [*Capsicum annuum* L. (Solanales: Solanaceae)] is cultivated worldwide, including in China, Mexico, Spain, United States and Brazil (Naegele, Mitchell and Hausbeck, 2016; FAOSTAT, 2018; Krauß and Vetter, 2019). The world production of bell pepper is 36 million tons in an area of 1,990,423 hectares (FAOSTAT, 2018). In recent years, interest in the consumption of bell pepper has increased due to its high nutritional value and its importance as a functional food rich in antioxidants (Simonne *et al.*, 1997; Ou *et al.*, 2002; Deepa *et al.*, 2006; Ghasemnezhad, Sherafati and Payvast, 2011; Chávez-Mendoza *et al.*, 2015).

The green peach aphid *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) is an important pest in pepper cultivations (Weintraub, 2007; Soares *et al.*, 2020). It is a highly polyphagous species, with approximately 400 species of host plants and vectoring about 100 plant viruses (Blackman, R. L., & Eastop, 2000; Van Emden and Harrington, 2017). The damage caused to plants is due to suction of phloem sap from the plant and transmission of viruses (Fenton *et al.*, 2010; Soares *et al.*, 2020). In addition, the sweet excretions of *M. persicae* favor the incidence of opportunistic fungi, which form a dark layer that covers leaves and fruits (black sooty mould). This fungus reduces both the photosynthetic activity of the plant and the quality of the product sold (Van Emden and Harrington, 2017).

The use of insecticides is the main method of controlling *M. persicae* in bell pepper cultivations. However, the intensive use of these products can lead to *M. persicae* control failures due to the selection of pest populations resistant to insecticides (Perring, Gruenhagen and Farrar, 1999; Foster, Denholm and Devonshire, 2000; Parker *et al.*, 2006; Bass *et al.*, 2014). Furthermore, the indiscriminate use of insecticides can increase production costs, contaminate the environment and cause impacts on beneficial organisms and human health (Desneux, Decourtye and Delpuech, 2007; Carvalho, 2017).

In this context, the use of decision-making systems in integrated pest management (IPM) programs make it possible to reduce the number of insecticide applications and consequently the production cost and the negative effects of these products (Pedigo, 1989; Higley and Pedigo, 1996; Picanço *et al.*, 2007; Bacci *et al.*, 2008). Sampling plans are essential components of decision-making systems (Lima *et al.*, 2017; Pinto *et al.*, 2017), and can be conventional (fixed number of samples) or sequential (variable number of samples) (Gusmão *et al.*, 2006; Pereira *et al.*, 2017; Lopes *et al.*, 2019). In many sampling plans, the crop area is divided into uniform plots and scouts perform evaluations at points distributed along the crop area. At each sampling point, the density of the pest or crop injury is evaluated (Pedigo and Buntin, 1993; L. Young and Young, 1998; Moura *et al.*, 2007; Rosado *et al.*, 2014; Lima *et al.*, 2017).

Conventional sampling plans are the starting point for generating decision-making systems in IPM programs (Castle and Naranjo, 2009; Lima *et al.*, 2017). Through it, it is possible to determine the level of economic damage and validate sequential sampling plans (Pedigo, Hutchins and Higley, 1986; Gusmão *et al.*, 2005; Bacci *et al.*, 2008). Sampling plans must be accurate, representative and practicable (Moura *et al.*, 2007; Lima *et al.*, 2017; Pinto *et al.*, 2017). Plans are feasible when they enable fast, low-cost sampling (Rosado *et al.*, 2014; Lima *et al.*, 2017; Pinto *et al.*, 2017).

In conventional sampling plans, the sampling unit, sampling technique and the number of samples per area are determined (Moura *et al.*, 2007; Rosado *et al.*, 2014; Pinto *et al.*, 2017). The sampling unit represents where the pest is present and may be a plant or part of the plant such as leaves, flowers and fruits. The sampling technique is the way of obtaining the samples, which can include direct counting on plants or throght the use of devices such as traps, tray and beat cloth (Moura *et al.*, 2003; Gusmão *et al.*, 2005; Bacci *et al.*, 2008). The selection of the best sampling unit and technique makes it possible to estimate the population density of the pest, taking into account criteria such as frequency, representativeness and precision, in order to provide support for correct decision making (Pedigo, 1989; Schuster, 1998; Bacci *et al.*, 2008).

Despite the importance of bell pepper and *M. persicae*, no studies have been conducted that examine convencional sampling plans for this aphid in this crop. The objective of this work was to develop a feasible conventional sampling plans for *M. persicae* in comercial bell pepper fields. Therefore, in this work, the sampling unit, sampling technique, number of samples and the time to sample, and costs of the sampling plan were determined.

# 2. MATERIALS AND METHODS

## 2.1 EXPERIMENTAL CHARACTERISTICS

This research was conducted during the years 2017-2019 in 26 commercial bell pepper (Magali cultivar) in Tocantins, state of Minas Gerais, Brazil (21°10′30″S, 43°01′18″W, altitude 364 m and tropical climate). In the bell pepper fields, the spacing between plants was 0.5 x 1.0 m and the plants were managed according to the recommended techniques by Filgueira (2008).

## 2.2. SAMPLING UNIT SELECTION

For sampling unit selection, two commercial bell pepper fields of about 5 ha each were selected; plants were in the vegetative stage in the first field and in the reproductive stage in the second field (Figure 1A). Thirty plants were randomly selected at each phenological stage and had all leaves evaluated. The leaves were numbered from the apex to the base, with the most apical leaf of the canopy receiving the number 1, the second most apical number 2, and so on. For each leaf, the density of *M. persicae* was determined using the direct counting technique (Figure 1B). This technique is a commonly used sampling method for initial evaluation of insect pest populations in cultivated fields (Lopes *et al.*, 2019; Paes *et al.*, 2019; Araújo *et al.*, 2020). Direct counting was performed on both sides of the leaves, which were carefully turned to prevent the aphids from falling (Bacci *et al.*, 2008; Pinto *et al.*, 2017; Silva *et al.*, 2019) (Figure 1B).

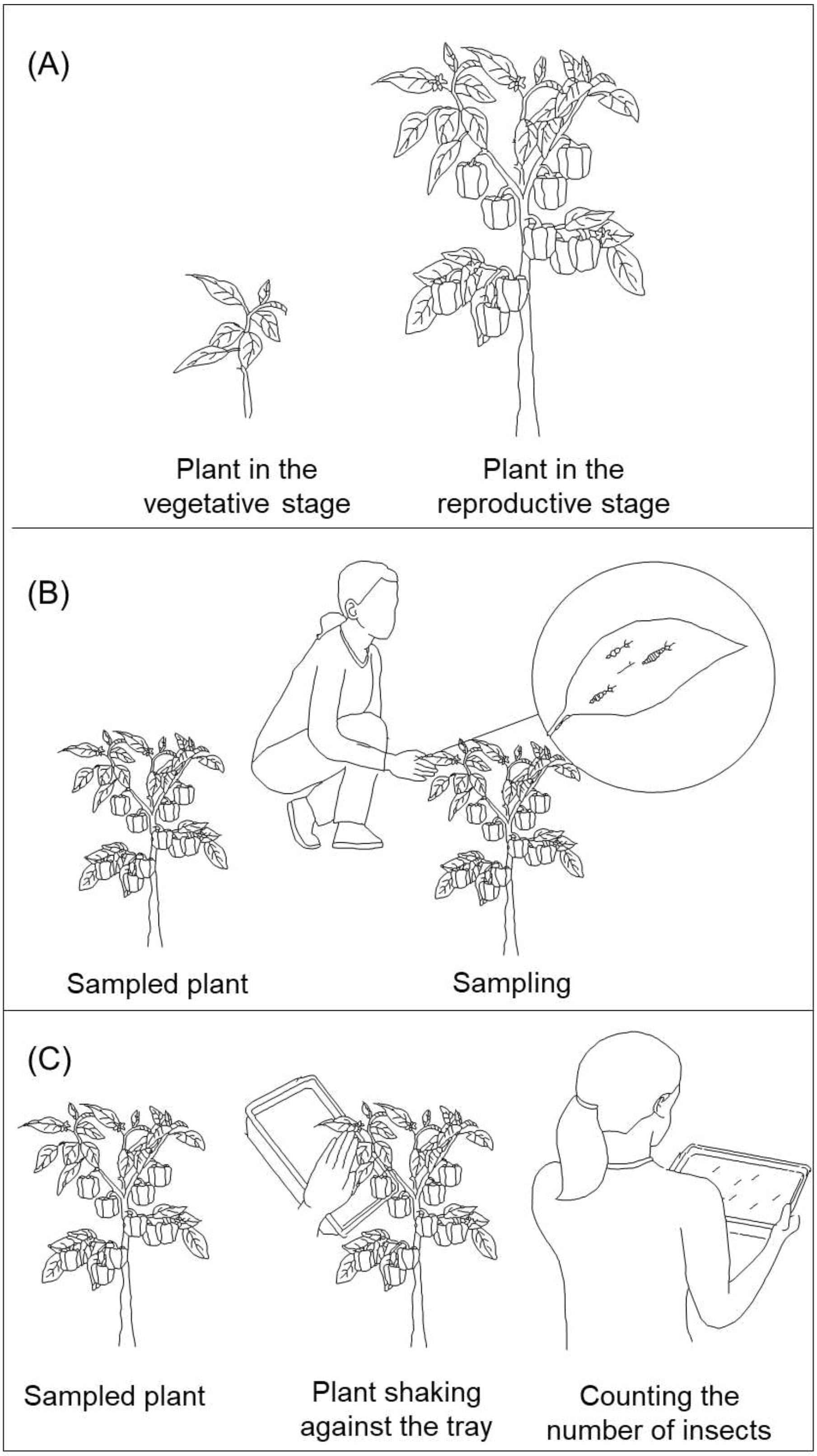


Figure 1. (A) Phenological stages of bell pepper plants, sampling of the aphid *Myzus persicae* using the techniques of (B) direct counting on plants and (C) beating the leaves in a plastic tray.

The selection of the appropriate sampling unit for evaluation of the *M. persicae* population in each phenological stage of the plants (vegetative or reproductive) was based on the criteria of frequency of occurrence of the leaf in the plant, precision and representativeness (Southwood, 1978; Pinto *et al.*, 2017; Silva *et al.*, 2019). Leaf occurrence frequency in the plant was calculated using the equation (1):

$Freq_i = (100 \times N_i)/Nt$, where $Freq_i$ is the leaf occurrence frequency in the plant (%), *i* is the leaf position in relation to the apical meristem (1 to *n*), $N_i$ is how many times leaf *i* was present in the evaluated plants, and *Nt* is the total number of evaluated plants. Leaves that showed frequency of occurrence in the plants higher than or equal to 80% were selected. This criterion was adopted due to the fact that plant structures with high frequency of occurrence are easily found in plants, contributing to a faster sampling (Pinto *et al.*, 2017).

The precision criterion used to select the sampling unit was the relative variance (RV) of *M. persicae* densities on each bell pepper leaf (Bacci *et al.*, 2008) using the following equation (2):

(2) $RV = 100 \times (SE/\bar{x})$, onde $RV$ is the relative variance (%), $(SE)$ is the standard error of *M. persicae* mean densities, and $\bar{x}$ is the mean densities. Sample units with relative variances lower than 25% were selected to generate feasible sampling plans (Southwood, 1978; Bacci *et al.*, 2008).

For the representativeness criterion, the relative densities (mean no. of aphids. leaf$^{-1}$) and the absolute density (mean no. of aphids. plant$^{-1}$) were calculated. Data on relative densities and absolute densities were subjected to Pearson correlation analysis. The sample units that showed positive and significant correlations ($P$ < 0.05) of the relative densities with the absolute density were selected. When more than one sample showed positive and significant correlations, simple linear regression analysis of the relative densities in these samples was performed as a function of absolute densities at $P$ < 0.05. The slopes of these regressions were compared using their 95% confidence intervals. Samples with highest angular coefficients were selected (Moura *et al.*, 2007; Bacci *et al.*, 2008; Rosado *et al.*, 2014). Statistical procedures were performed in R version 3.5.3 and RStudio version 1.2.5001 (R Core Team, 2013).

## 2.3. SAMPLING TECHNIQUE SELECTION

This part of the work was carried out in two commercial bell pepper fields of about 5 ha with plants in the vegetative stage in the first field and in the reproductive stage in the second field (Figure 1A). In each field, 20 plants were selected at random. Two techniques for sampling *M. persicae* were evaluated: direct counting on the plant and beating the leaves of the plants on a white plastic tray. The direct counting technique consisted of direct counting of the insects in the sample previously selected in section 2.1 (Figure 1B). The beating technique consisted of shaking the sample selected previously in a white plastic tray (40 × 25 × 3 cm), followed by counting the number of *M. persicae* (Figure 1C). These two techniques were used because they are among the main techniques used in the sampling of sucking insects such as aphids (Gusmão *et al.*, 2005; Araújo *et al.*, 2019; Macêdo *et al.*, 2019).

During the evaluations, the aphid density and sampling time were recorded. *M. persicae* densities (mean ± SE) were calculated for each sampling technique. The technique was selected according to the criteria of precision and shorter sampling time. The sampling technique in which the density of *M. persicae* presented a relative variance of less than 25% was selected based on the precision criterion, as previously described (Southwood, 1978; Bacci *et al.*, 2008).

Data on aphid densities and sampling time as a function of sampling techniques in each of the 20 plants in the vegetative and reproductive stage were subjected to the paired t test ($P < 0.05$) using the software R version 3.5.3 and RStudio version 1.2.5001 (R Core Team, 2013). The technique with the shortest sampling time was selected. This technique was chosen because less time-consuming techniques generate more viable and low-cost sampling plans (Moura *et al.*, 2007; Bacci *et al.*, 2008).

## 2.4. DETERMINATION OF FREQUENCY DISTRIBUTION OF PEST DENSITIES

Research was carried out in 19 commercial bell pepper fields. In each field, the density of *M. persicae* was evaluated on 300 plants, which were distributed equidistantly (Rosado *et al.*, 2014; Pinto *et al.*, 2017). The densities of *M. persicae* were evaluated using the sampling units and the sampling technique selected in the previous evaluations.

For each field, the means and standard errors of the *M. persicae* densities were calculated. Frequency distributions (negative binomial, Poisson and positive binomial) were determined for the *M. persicae* density data in each field. It was considered that the *M. persicae* densities fit a frequency distribution when the expected and observed frequencies were statistically simliar according to a Chi-square test ($P > 0.05$) (Rosado *et al.*, 2014). The frequency distribution selected was the one that adjusted to pest densities in most fields (L. . Young and Young, 1998; Moura *et al.*, 2007; Rosado *et al.*, 2014).

**2.5. DETERMINATION OF THE NUMBER OF SAMPLES**

Because most fields adjusted to the negative binomial distribution in our study, the values of the aggregation parameter for each field were calculated according to equation (3) (L. . Young and Young, 1998):

(3) $k = \overline{x}^2/(S^2 - \overline{x})$ , where: $k$ is the parameter of the negative binomial distribution, $\overline{x}^2$ is the mean, and $S^2$ is the variance of *M. persicae* density in the field.

To verify the existence of a common aggregation parameter ($K_{common}$), which represented all fields of bell pepper, the k value of each field was submitted to simple linear regression analysis (Bliss and Owen, 1958). In this analysis, bell pepper fields had a $K_{common}$ value when the regression has a significant slope or a nonsignificant intercept (Bliss and Owen, 1958).

After verifying the existence of a $K_{common}$ across the bell pepper fields, the number of samples to compose the sampling plan of *M. persicae* was estimated using equation (4) (L. . Young and Young, 1998):

(4) $\text{NA} = \frac{1}{C^2}\left(\frac{1}{\bar{x}} + \frac{1}{k_c}\right)$, where: NA is the number of samples, C is the maximum allowed error, $\bar{x}$ is the population mean, and $k_c$ is the common agregation parameter of the negative binomial model.

Subsequently, the error to be used in calculating the number of samples per field was determined. For this purpose, the number of samples per field was calculated according to the sampling error. The error values used were 0.05 (5%), 0.10 (10%), 0.15 (15%), 0.20 (20%) and 0.25 (25%) (Moura *et al.*, 2007; Pinto *et* *al.*, 2017). These errors values were used because they are considered acceptable for pest sampling plans for IPM programs (Bacci *et al.*, 2008; Lopes *et al.*, 2019; Silva *et al.*, 2019).

### 2.6. TIME AND COST OF THE SAMPLING PLAN AS A FUNCTION OF FIELD SIZE

Samples were collected in commercial bell pepper fields with areas of 1, 5 and 10 ha. These fields were selected as they are representative of comercial bell pepper fields in Brazil. For sampling, the sample and the number of samples previously determined were used. The distance covered, the walking time and the time for the evaluation of the samples in each field were determined (Bacci *et al.*, 2008; Araújo *et al.*, 2019; Lopes *et al.*, 2019).

Costs for *M. persicae* sampling in each of the three field sizes were then calculated. In these calculations, the costs of rural worker wage and the materials used in the sampling (paper, pencil, rubber and clipboard) were considered (Moura *et al.*, 2007; Lopes *et al.*, 2019; Araújo *et al.*, 2020).

## 3. RESULTS

### 3.1. SAMPLING UNIT

At the vegetative stage, the 10 most apical leaves had frequencies of occurrence above 80%. The densities of *M. persicae* showed relative variances below 25% from the 1$^{st}$ to the 7$^{th}$ leaves and 9$^{th}$ leaf. In the 1$^{st}$, 4$^{th}$, 5$^{th}$, 7$^{th}$ and 9$^{th}$ leaves the relative densities (mean no. of aphids. leaf$^{-1}$) showed significant correlations ($P$ < 0.05) with the absolute densities (mean no. of aphids. plant$^{-1}$). The 5$^{th}$ leaf had the highest angular coefficient among regressions relating relative density with absolute density (Table 1). Therefore, the adequate sample for the evaluation of *M. persicae* populations in bell pepper plants in the vegetative stage was the 5$^{th}$ most apical leaf.

**Table 1.** Selection of the sample to be used in the evaluation of aphid populations of *Myzus persicae* in bell pepper fields with plants in the vegetative and reproductive stages: frequency of occurrence of the leaf in this position of the plant, relative aphid density (mean ± standard error), relative variance (RV), Pearson correlation (r) between relative densities (aphids. leaf$^{-1}$) and absolute

density (aphids. plant$^{-1}$) and (b) slope of the regression relating relative density absolute density.

| § Leaf position | Frequency (%) | Aphid sampling characteristics. | | | |
|---|---|---|---|---|---|
| | | Density | RV (%) | r | b ± SE |
| | | Vegetative stage plants | | | |
| 1 | 100.00 | 1.75 ± 0.32 | 18.01 | 0.61* | 0.07* ± 0.02 |
| 2 | 100.00 | 4.65 ± 0.71 | 15.31 | $0.02^{ns}$ | - |
| 3 | 100.00 | 5.10 ± 0.71 | 13.93 | $0.34^{ns}$ | - |
| 4 | 100.00 | 3.65 ± 0.84 | 23.12 | 0.40* | 0.12* ± 0.06 |
| 5 | 100.00 | 4.30 ± 1.07 | 24.80 | 0.70* | 0.26* ± 0.06 |
| 6 | 100.00 | 2.85 ± 0.41 | 14.46 | $0.24^{ns}$ | - |
| 7 | 100.00 | 2.55 ± 0.47 | 18.32 | 0.74* | 0.12*±0.03 |
| 8 | 100.00 | 1.35 ± 0.43 | 31.92 | 0.46* | 0.07* ± 0.03 |
| 9 | 95.00 | 1.26 ± 0.27 | 21.70 | 0.41* | $0.04^{ns}$ ± 0.02 |
| 10 | 80.00 | 2.50 ± 1.59 | 63.77 | - | - |
| 11 | 55.00 | 0.73 ± 0.38 | 52.74 | - | - |
| 12 | 20.00 | 0.50 ± 0.50 | 100.00 | - | - |
| 13 | 10.00 | 1.00 ± 0.00 | 0.00 | - | - |
| | | Reproductive stage plants | | | |
| 1 | 100.00 | 1.60 ± 0.29 | 18.13 | 0.39* | 0.06* ± 0.03 |
| 2 | 100.00 | 2.97 ± 0.34 | 11.48 | $0.26^{ns}$ | - |
| 3 | 100.00 | 9.77 ± 0.68 | 6.92 | 0.82* | 0.30* ± 0.04 |
| 4 | 100.00 | 2.60 ± 0.39 | 14.82 | 0.34* | 0.07* ± 0.04 |
| 5 | 100.00 | 1.83 ± 0.35 | 19.23 | 0.38* | 0.07* ± 0.03 |
| 6 | 100.00 | 2.00 ± 0.35 | 17.45 | $0.26^{ns}$ | - |
| 7 | 100.00 | 0.97 ± 0.29 | 29.96 | 0.38* | 0.06* ± 0.03 |
| 8 | 100.00 | 0.73 ± 0.22 | 29.91 | $0.29^{ns}$ | - |
| 9 | 100.00 | 0.97 ± 0.32 | 32.71 | 0.47* | 0.08* ± 0.03 |
| 10 | 100.00 | 1.03 ± 0.24 | 23.42 | 0.36* | 0.05* ± 0.02 |
| 11 | 100.00 | 0.67 ± 0.21 | 30.79 | $-0.13^{ns}$ | - |
| 12 | 100.00 | 0.93 ± 0.28 | 29.48 | $0.12^{ns}$ | - |
| 13 | 93.33 | 1.36 ± 0.50 | 37.17 | $0.20^{ns}$ | - |
| 14 | 93.33 | 1.07 ± 0.41 | 38.08 | 0.39* | 0.08 ± 0.04 |
| 15 | 43.33 | 1.23 ± 0.50 | 40.26 | - | - |
| 16 | 33.33 | 1.00 ± 0.51 | 50.99 | - | - |
| 17 | 6.67 | 3.50 ± 2.50 | 71.43 | - | - |

§ 1, 2 and n = 1st, 2nd and nth leaf from the apex of the branch, respectively.

At the reproductive stage, the 14 most apical leaves of the plant had frequencies of occurrence above 80%. In the 1st, 2nd, 3rd, 4th, 5th, 6th and 10th leaves, the densities of *M. persicae* showed relative variances below 25%. In the 1st, 3rd, 4th, 5th and 10th leaves the relative densities (mean no. of aphids. leaf$^{-1}$) were significantly correlated ($P$ < 0.05) with the absolute densities (mean no. aphids. plant$^{-1}$). The 3rd leaf had the highest angular coefficient among regressions relating relative density with absolute density (Table 1). Therefore, the adequate sample for the evaluation of *M. persicae* populations in commercial bell pepper 'Magali' in the reproductive stage was the 3rd most apical leaf.

### 3.2. SAMPLING TECHNIQUE

In bell pepper plants, *M. persicae* densities sampled by the beating of plants in a white plastic tray were significantly higher ($P < 0.05$) than the densities evaluated using the direct counting technique (Figure 2A). The variances of the *M. persicae* densities evaluated by the two techniques were less than 25% (Figure 2B). The sampling time of *M. persicae* using the beating technique with a white plastic tray was significantly lower ($P < 0.05$) than the sampling time of the direct counting technique. Similar trends were noted for plants in both the vegetative and reproductive stages (Figure 2C). Therefore, the best technique for sampling *M. persicae* in bell pepper fields was the beating of the apical part of the plants in a white plastic tray.

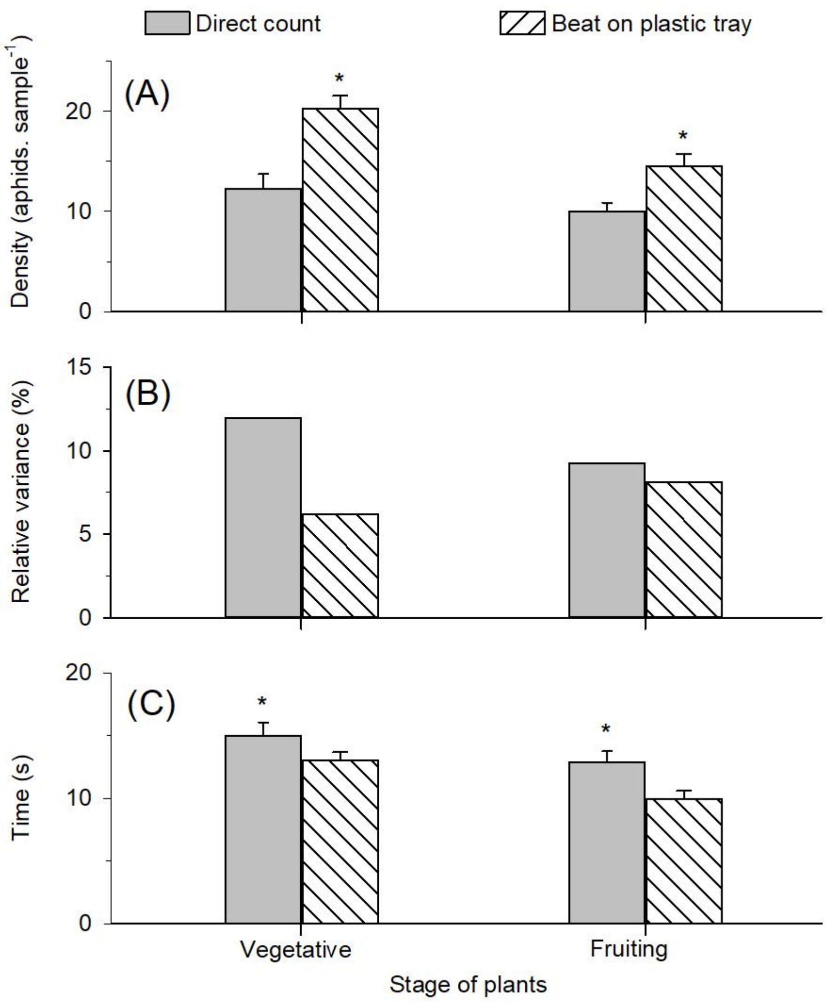

**Figure 2.** Selection of the sampling technique: (A) density of *Myzus persicae*, (B) relative variance and (C) sampling time (mean ± standard error) using the direct counting techniques (using the best selected sample shown in the Table 1) and beating leaves in a plastic tray. At each plant stage, the means followed by the same lower case letter do not differ, according to the t test paired at $P < 0.05$.

### 3.3. FREQUENCY DISTRIBUTION OF *M. PERSICAE* DENSITIES

In 15 of the 19 bell pepper fields evaluated (78.95%), the observed distributions of *M. persicae* did not differ significantly from the negative binomial frequency distribution ($P > 0.05$). In all bell pepper fields, the observed *M. persicae* distributions differed significantly from both the Poisson and positive binomial distributions (Table 2). Thus, the number of samples from *M. persicae* coventional sampling plan in bell pepper fields was calculated using the negative binomial frequency distribution equation.

**Table 2.** Chi-square test ($\chi^2$) between the frequencies observed and expected by the negative binomial, Poisson and positive binomial distributions of the densities (mean ± error) of the aphid *Myzus persicae* in 19 commercial bell pepper fields sampled by beating the leaves in a plastic tray.

| Field | Density | Negative binomial | | Poisson | | Positive binomial | |
|---|---|---|---|---|---|---|---|
| | | $\chi^2$ | df | $\chi^2$ | df | $\chi^2$ | df |
| 1 | 0.38 ± 0.053 | 2.11 $^{ns}$ | 4 | $1.80{\times}10^{4*}$ | 5 | $3.46{\times}10^{3*}$ | 5 |
| 2 | 0.49 ± 0.096 | 4.71 $^{ns}$ | 4 | $8.23{\times}10^{3*}$ | 5 | $2.10{\times}10^{3*}$ | 5 |
| 3 | 0.30 ± 0.049 | 5.08 $^{ns}$ | 2 | 61.06$^{*}$ | 3 | $1.41{\times}10^{3*}$ | 3 |
| 4 | 3.21 ± 0.510 | 19.05 $^{ns}$ | 11 | $3.07{\times}10^{4*}$ | 12 | $1.07{\times}10^{11*}$ | 12 |
| 5 | 1.40 ± 0.197 | 17.23$^{*}$ | 7 | $2.75{\times}10^{4*}$ | 8 | $6.29{\times}10^{9*}$ | 8 |
| 6 | 0.33 ± 0.083 | 8.00$^{ns}$ | 4 | $5.73{\times}10^{3*}$ | 5 | $7.07{\times}10^{2*}$ | 5 |
| 7 | 3.06 ± 0.700 | 10.10$^{ns}$ | 11 | $1.91{\times}10^{4*}$ | 12 | $4.81{\times}10^{12*}$ | 12 |
| 8 | 1.44 ± 0.294 | 19.93$^{*}$ | 7 | $3.71{\times}10^{3*}$ | 8 | $1{,}26.10^{10*}$ | 8 |
| 9 | 0.27 ± 0.051 | 0.75$^{ns}$ | 1 | 11.73$^{*}$ | 2 | 88.29$^{*}$ | 2 |
| 10 | 3.36 ± 0.742 | 12.63$^{ns}$ | 7 | $1.24{\times}10^{3*}$ | 8 | $4.87{\times}10^{13*}$ | 8 |
| 11 | 1.36 ± 0.261 | 5.62$^{ns}$ | 5 | $9.71{\times}10^{2*}$ | 6 | $1.48{\times}10^{6*}$ | 6 |
| 12 | 0.16 ± 0.024 | 0.19 $^{ns}$ | 1 | 7.17$^{*}$ | 2 | 131.88$^{*}$ | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 13 | 1.61 ± 0.170 | 22.90* | 13 | $2.19\times10^{8*}$ | 14 | $1.31\times10^{8*}$ | 14 |
| 14 | 0.15 ± 0.032 | $2.27^{ns}$ | 1 | 10.33 | 2 | $65.20^{*}$ | 2 |
| 15 | 1.74 ± 0.243 | $14.23^{*}$ | 7 | $8.29\times10^{3*}$ | 8 | $4.79\times10^{6*}$ | 8 |
| 16 | 1.50 ± 0.372 | $21.84^{ns}$ | 14 | $3.02\times10^{9*}$ | 15 | $1.48\times10^{6*}$ | 15 |
| 17 | 0.17 ± 0.035 | $2.30^{ns}$ | 1 | 8.72* | 1 | $37.66^{*}$ | 1 |
| 18 | 1.47 ± 0.237 | $10.04^{ns}$ | 8 | $4.15\times10^{4*}$ | 9 | $3.46\times10^{7*}$ | 9 |
| 19 | 1.17 ± 0.239 | $13.90^{ns}$ | 7 | $1.32\times10^{4*}$ | 8 | $1.15\times10^{7*}$ | 8 |

$^{ns}$ nonsignificant. *Significant at 5% probability. df = Degrees of freedom

### 3.4. NUMBER OF SAMPLES FOR THE CONVENTIONAL SAMPLING PLAN

The regression between the aggregation parameter ($K_{common}$) and the K parameter of each bell pepper field had a significant slope (*P* < 0.05) and a nonsignificant intercept (*P* > 0.05) (Table 3). Therefore, there was a common aggregation parameter ($K_{common}$ = 0.1816) between *M. persicae* densities in all bell pepper fields.

**Table 3.** Analysis of variance of *Myzus persicae* densities data, sampled in 19 bell pepper cultivation fields using the tray beating technique, to verify homogeneity for the $K_{common}$ parameter of the negative binomial distribution.

| Factors | Degrees of freedom | Sum of squares | Mean Squares | F |
|---|---|---|---|---|
| Slope 1/kcommon | 1 | 176.69 | 17.69 | 11.78* |
| Intercept | 1 | 5.98 | 5.98 | 3.79 $^{ns}$ |
| Residual | 16 | 25.29 | 1.58 | |
| $K_{common}$ = 0.1816 | | | | |

$^{ns}$ nonsignificant. * Significant at 5% probability.

The number of samples required for sampling *M. persicae* stabilized when it reached the maximum allowed error of 20%. Thus, a 20% error was adopted in calculating the number of samples in the conventional sampling plan. Using this criterion, the number of samples required for the evaluation of *M. persicae* populations in bell pepper fields was 158 samples (Fig. 3).

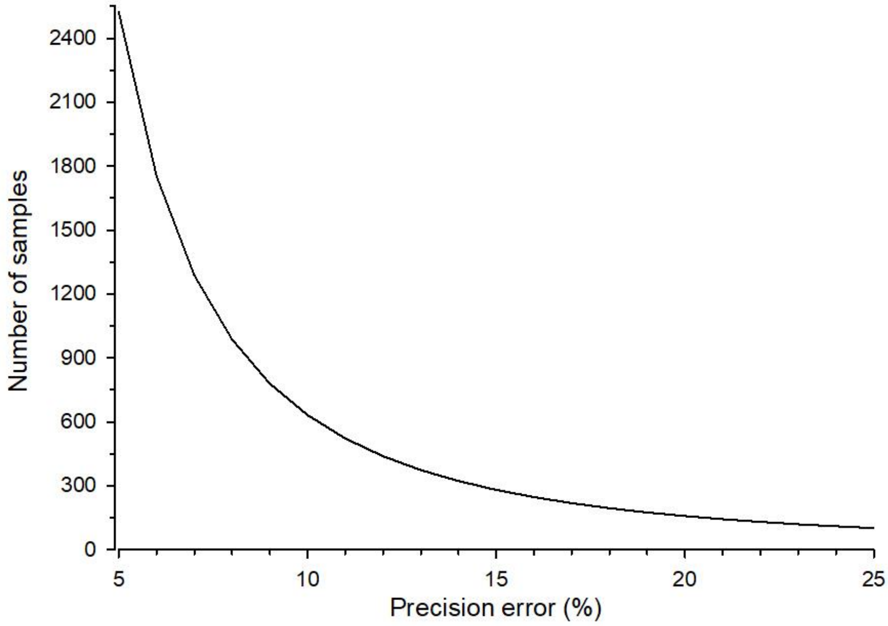


**Figure 3.** Number of samples of *Myzus persicae*, as a function of different precision error levels.

### 3.5. TIME AND COST OF SAMPLING PLAN AS A FUNCTION OF FIELD SIZE

In bell pepper fields of 1, 5 and 10 hectares, the distances covered for sampling were 1,200.00, 2,683.28 and 3,794.73 meters, respectively. The walking time between samples was 12, 27 and 38 min in areas with 1, 5 and 10 ha, respectively. The time required to evaluate the 158 samples in any field was 30 min. Therefore, the total time for sampling *M. persicae* was 42 min, 57 min and 1 hour and 08 min for bell pepper fields of 1, 5 and 10 ha, respectively. The total cost of a sampling of *M. persicae* was US$ 1.19, US$ 1.59 and US$ 1.90 for fields of 1, 5 and 10 ha, respectively (Table 4).

**Table 4.** Time, distance walking and cost required for sampling *Myzus persicae* in bell pepper fields as a function of the field size

| Field size (ha) | Distance walking (m) | Walking between samples | | Evaluation | | Sampling time | Sampling cost(US$) |
|---|---|---|---|---|---|---|---|
| | | Time | (%) | Time | (%) | | |
| 1 | 1200.00 | 12 min | 28.57 | 30 | 71.43 | 42 min | 1.19 |
| 5 | 2683.28 | 27 min | 47.37 | 30 | 52.63 | 57 min | 1.59 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10 | 3794.73 | 38 min | 55.88 | 30 | 44.12 | 1h 08 min | 1.90 |

## 4. DISCUSSION

The ideal samples for evaluating *M. persicae* populations in bell pepper fields had the highest densities, which were found in the apical section of the plant. This is likely due to the leaves being young and thus have softer tissues with better nutritional quality (Gusmão *et al.*, 2005; Bernays and Chapman, 2007; Bacci *et al.*, 2008; Pereira *et al.*, 2016).

The best technique for sampling *M. persicae* in bell pepper fields was the beating of the apical part of the plants in a white plastic tray. This was due to the fact that this technique had a shorter sampling time, while also being accurate (relative variance < 25%). In addition, this technique made it possible to evaluate higher pest densities in relation to the direct aphid counting on the leaf. The fact that a technique has a shorter sampling time indicates that its use will enable the generation of sampling plans that are easier to be adopted by consultants and producers (Moura *et al.*, 2007; Bacci *et al.*, 2008; Pinto *et al.*, 2017; Araújo *et al.*, 2019). The use of precise techniques will generate plans with a smaller number of samples which are more practical (Gusmão *et al.*, 2005; Moura *et al.*, 2007; Rosado *et al.*, 2014). In addition, techniques with fast sampling contribute to the low-cost sampling plans that can help pest control decisions to be made prior to economic damage (Gusmão *et al.*, 2005; Lima *et al.*, 2014; Pinto *et al.*, 2017).

The beating of the apical part of the plants in a white plastic tray was the most appropriate technique for evaluating *M. persicae* in plants of both phenological stages (vegetative and reproductive). This fact is important since, when the direct counting technique was adopted, the ideal samples for evaluating the pest on plants in the vegetative stage (5$^{th}$ most apical leaf) and reproductive stage (3$^{rd}$ most apical leaf) were different. Thus, the use of the beating of the apical part of the plants in a plastic tray throughout the season will simplify sampling plans that may therefore be more readily adopted by farmers.

The distributions of *M. persicae* in most fields of bell pepper (78.95%) did not differe from the negative binomial distribution. This occurred because the variances were greater than the average densities (Taylor, 1961; Moura *et al.*, 2007; Rosado *et al.*, 2014). The frequency distribution model is essential for the selection of the equation to be used in the calculation of the number of samples in the sampling plan (Gusmão *et al.*, 2005; Pinto *et al.*, 2017). It is important to note that the frequency distribution of insect densities does not provide information on the spatial distribution of insects in cultivated fields, as this determination does not take into account the location of samples (Young and Young, 1990; Barrigossi *et al.*, 2001; Silva *et al.*, 2019).

In all bell pepper fields, the densities of *M. persicae* showed a common aggregation parameter, indicating that the sampling plan determined in this work can be used in different bell pepper fields (Bliss and Owen, 1958; L. . Young and Young, 1998; Rosado *et al.*, 2014; Lima *et al.*, 2017). Another important aspect is that this common aggregation parameter was developed for bell pepper plants in both the vegetative and reproductive stages. This simplifies the sampling plan and makes it more likely to be adopted by farmers. It is also worth mentioning that populations of a species can have different values for the aggregation parameter of the negative binomial distribution in different fields. Different values of this parameter require the calculation of the number of samples for each field, which makes it difficult to determine a sampling plan that can be used in different fields (Young and Young, 1998; Araújo *et al.*, 2019; Lopes *et al.*, 2019).

The sampling plan generated in this work was feasible because it made it was quick (less than 1 h), inexpensive (until US$ 1.90) and had a low error (maximum error of 20%). Sampling plans are feasible when they enable quick, low-cost and efficient decisions (Gusmão *et al.*, 2005; Lima *et al.*, 2014). The evaluation of pest densities in the field and the processing of data need to be fast so that decision-making takes place within the same day (Gusmão *et al.*, 2005; Moura *et al.*, 2007; Rosado *et al.*, 2014). This is important for control measures to be quickly implemented at the appropriate time, avoiding economic losses (Rosado *et al.*, 2014; Pinto *et al.*, 2017). The adoption of adequate decision-making systems, which include practical sampling plans, avoids the unnecessary use of pest control methods, which reduces production costs and contributes to the preservation of the environment, human health and populations of non-target organisms (Picanço *et al.*, 2004; Bacci *et al.*, 2008; Lima *et al.*, 2017).

## 5. CONCLUSIONS

The sampling plan developed in this study to evaluate populations of the aphid *M. persicae* in bell pepper crops can be incorporated into integrated pest management programs because it is practical, accurate, fast (up to 1 h and 8 min), and low cost (up to US$ 1.90 per sample). In this plan, the crop area should be divided into plots of up to 10 ha. In each plot, the apical part of 158 plants must be sampled by beating in a white plastic tray. These plants must be distributed throughout the growing area. The number of aphids in the bottom of the white plastic tray should be counted.

## 6. REFERENCES


Ames, B. N., Shigenaga, M. K. and Hagen, T. M. (1993) ‘Oxidants, antioxidants, and the degenerative diseases of aging’, *Proceedings of the National Academy of Sciences of the United States of America*, 90(17), pp. 7915–7922. doi: 10.1073/pnas.90.17.7915.

Araújo, T. A. *et al.* (2019) ‘Standardized sampling plan for Aphis gossypii based on the cotton cultivar, plant phenology and crop size’, *Journal of Applied Entomology*, 143(8), pp. 893–901. doi: 10.1111/jen.12639.

Araújo, T. A. de *et al.* (2020) ‘Development and validation of sampling plans for Frankliniella schultzei on tomato’, *Crop Protection*. Elsevier Ltd, 134, pp. 105–163. doi: 10.1016/j.cropro.2020.105163.

Bacci, L. *et al.* (2008) ‘Sampling plan for thrips (Thysanoptera: Thripidae) on cucumber’, *Neotropical Entomology*, 37(5), pp. 582–590. doi: 10.1590/S1519-566X2008000500014.

Barrigossi, J. A. F. *et al.* (2001) ‘Spatial and probability distribution of mexican bean beetle (Coleoptera: Coccinellidae) egg mass populations in dry bean’, *Environmental Entomology*, 30(2), pp. 244–253. doi: 10.1603/0046-225X-30.2.244.

Bass, C. *et al.* (2014) ‘The evolution of insecticide resistance in the peach potato aphid, Myzus persicae’, *Insect Biochemistry and Molecular Biology*. Elsevier Ltd, 51(1), pp. 41–51. doi: 10.1016/j.ibmb.2014.05.003.

Bernays, E. . and Chapman, R. . (2007) *Host-plant selection by phytophagous insects.* Springer Science & Business Media.

Blackman, R. L., & Eastop, V. F. (2000) *Aphids on the world’s crops: an identification and information guide*. 2nd edn. John Wiley & Sons Ltd.

Bliss, C. I. and and Owen, A. R. G. (1958) ‘Negative binomial distributions with a common k.’, *Biometrika*, Vol. 45(1/2), pp. 37–58.

Carvalho, F. P. (2017) ‘Pesticides, environment, and food safety’, *Food and Energy Security*, 6(2), pp. 48–60. doi: 10.1002/fes3.108.

Castle, S. and Naranjo, S. E. (2009) ‘Sampling plans, selective insecticides and sustainability: The case for IPM as “informed pest management”’, *Pest Management Science*, 65(12), pp. 1321–1328. doi: 10.1002/ps.1857.

Chávez-Mendoza, C. *et al.* (2015) ‘Bioactive compounds and antioxidant activity in different grafted varieties of bell pepper’, *Antioxidants*, 4(2), pp. 427–446. doi: 10.3390/antiox4020427.

Deepa, N. *et al.* (2006) ‘Antioxidant activity in some red sweet pepper cultivars’, *Journal of Food Composition and Analysis*, 19(6–7), pp. 572–578. doi: 10.1016/j.jfca.2005.03.005.

Desneux, N., Decourtye, A. and Delpuech, J.-M. (2007) ‘The Sublethal Effects of Pesticides on Beneficial Arthropods’, *Annual Review of Entomology*, 52(1), pp. 81–106. doi: 10.1146/annurev.ento.52.110405.091440.

Van Emden, H. F. and Harrington, R. (2017) *Aphids as crop pests*. CABI.

FAOSTAT (2018) *FAO Statistical Databases.* Available at: http://www.fao.org/faostat/en/#data/QC (Accessed: 28 July 2020).
Fenton, B. *et al.* (2010) 'Reproductive performance of asexual clones of the peach-potato aphid, (Myzus persicae, Homoptera: Aphididae), colonising Scotland in relation to host plant and field ecology', *Bulletin of Entomological Research*, 100(4), pp. 451–460. doi: 10.1017/S0007485309990447.

Filgueira, E. A. R. (2008) *Novo manual de Olericultura: agrotecnologia moderna na produção e comercialização de hortaliças*. 3rd edn. Edited by Editora UFV. Viçosa, Brasil.

Foster, S. P., Denholm, I. and Devonshire, A. L. (2000) 'The ups and downs of insecticide resistance in peach-potato aphids (Myzus persicae) in the UK', *Crop Protection*, 19, pp. 873–879. doi: 10.1016/S0261-2194(00)00115-0.

Ghasemnezhad, M., Sherafati, M. and Payvast, G. A. (2011) 'Variation in phenolic compounds, ascorbic acid and antioxidant activity of five coloured bell pepper (Capsicum annum) fruits at two different harvest times', *Journal of Functional Foods*. Elsevier Ltd, 3(1), pp. 44–49. doi: 10.1016/j.jff.2011.02.002.

Gusmão, M. R. *et al.* (2005) 'Standardised sampling plan for Bemisia tabaci (Homoptera: Aleyrodidae) in outdoor tomatoes', *Scientia Horticulturae*, 103(4), pp. 403–412. doi: 10.1016/j.scienta.2004.04.005.

Gusmão, M. R. *et al.* (2006) 'Economic injury level and sequential sampling plan for Bemisia tabaci in outdoor tomato', *Journal of Applied Entomology*, 130(3), pp. 160–166. doi: 10.1111/j.1439-0418.2005.01032.x.

Higley, L. G. and Pedigo, L. P. (1996) *Economic Thresholds for Integrated Pest Management*, *University of Nebraska Press, Lincoln, NE*.

Kaur, C. and Kapoor, H. C. (2001) 'Antioxidants in fruits and vegetables - The millennium's health', *International Journal of Food Science and Technology*, 36(7), pp. 703–725. doi: 10.1046/j.1365-2621.2001.00513.x.

Krauß, S. and Vetter, W. (2019) 'Stable Carbon and Nitrogen Isotope Ratios of Red Bell Pepper Samples from Germany, the Netherlands, and Spain', *Journal of Agricultural and Food Chemistry*. American Chemical Society, 67(14), pp. 4054–4063. doi: 10.1021/acs.jafc.9b01631.

Lima, C. H. O. *et al.* (2014) 'Efficiency and Economic Feasibility of Pest Control Systems in Watermelon Cropping', *Journal of Economic Entomology*, 107(3), pp. 1118–1126. doi: 10.1603/EC13512.

Lima, C. H. O. *et al.* (2017) 'Feasible sampling plan for Bemisia tabaci control decision-making in watermelon fields', *Pest Management Science*, 73(11), pp. 2345–2352. doi: 10.1002/ps.4621.

Lopes, M. C. *et al.* (2019) 'Practical Sampling Plan for Liriomyza huidobrensis (Diptera: Agromyzidae) in Tomato Crops', *Journal of Economic Entomology*, 112(4), pp. 1946–1952. doi: 10.1093/jee/toz091.

Macêdo, R. V. B. T. De *et al.* (2019) 'Sampling Plan for Bemisia tabaci (Hemiptera: Aleyrodidae) in Melon Crops', *Florida Entomologist*, 102(1), pp. 16–23. doi: 10.1653/024.102.0103.

Moura, M. F. *et al.* (2007) 'Conventional sampling plan for the green leafhopper Empoasca kraemeri in common beans', *Journal of Applied Entomology*, 131(3), pp. 215–220. doi: 10.1111/j.1439-0418.2006.01113.x.

Moura, M. F. de *et al.* (2003) 'Plano de amostragem do biótipo B de *Bemisia tabaci* na cultura do pepino', *Pesquisa Agropecuária Brasileira*, 38(12), pp. 1357–1363. doi: 10.1590/S0100-204X2003001200001.

Naegele, R. P., Mitchell, J. and Hausbeck, M. K. (2016) 'Genetic diversity, population structure, and heritability of fruit traits in capsicum annuum', *PLoS ONE*, 11(7), pp. 1–17. doi: 10.1371/journal.pone.0156969.

Ou, B. *et al.* (2002) 'Analysis of antioxidant activities of common vegetables employing oxygen radical absorbance capacity (ORAC) and ferric reducing antioxidant power (FRAP) assays: A comparative study', *Journal of Agricultural and Food Chemistry*, 50(11), pp. 3122–3128. doi: 10.1021/jf0116606.

Paes, J. S. *et al.* (2019) 'Economic injury level for sequential sampling plan of Frankliniella schultzei in bell pepper crops', *Crop Protection*, 123, pp. 30–35. doi: 10.1016/j.cropro.2019.05.011.

Parker, W. E. *et al.* (2006) 'The effect of insecticide application sequences on the control and insecticide resistance status of the peach-potato aphid, Myzus persicae (Hemiptera:Aphididae), on field crops of potato', *Pest Management Science*, 62(4), pp. 307–315. doi: 10.1002/ps.1162.

Pedigo, L. P. (1989) 'Entomology and pest management.', *Entomology and pest management.* Macmillan Publishing Company. Available at: https://www.cabdirect.org/cabdirect/abstract/19911156949 (Accessed: 12 July 2018).

Pedigo, L. P., Hutchins, S. H. and Higley, L. G. (1986) 'Economic Injury Levels in Theory and Practice', *Annual Review of Entomology*, 31(1), pp. 341–368. doi: 10.1146/annurev.ento.31.1.341.

Pereira, P. S. *et al.* (2017) 'Economic injury levels and sequential sampling plans for Frankliniella schultzei in watermelon crops', *Pest Management Science*, 73(7), pp. 1438–1445. doi: 10.1002/ps.4475.

Perring, T. M., Gruenhagen, N. M. and Farrar, C. A. (1999) 'Management of Plant Viral Diseases Through Chemical Control of Insect Vectors', *Annual Review of Entomology*, 44(1), pp. 457–481. doi: 10.1146/annurev.ento.44.1.457.

Picanço, M. C. *et al.* (2004) 'Impactos financeiros da adoção de manejo integrado de pragas na cultura do tomateiro', *Acta Scientiarum. Agronomy*, 26(2), pp. 245–252. doi: 10.4025/actasciagron.v26i2.1889.

Picanço, M. C. *et al.* (2007) 'Effect of integrated pest management practices on tomato production and conservation of natural enemies', *Agricultural and Forest Entomology*, 9(4), pp. 327–335. doi: 10.1111/j.1461-9563.2007.00346.x.

Pinto, C. B. *et al.* (2017) 'Standardized Sampling Plan for the Thrips Frankliniella schultzei (Thysanoptera: Thripidae) on Watermelon Crops', *Journal of Economic Entomology*. Oxford University Press, 110(2), pp. 748–754. doi: 10.1093/jee/tow314.

Rosado, J. F. *et al.* (2014) 'Sampling plans for pest mites on physic nut', *Experimental and Applied Acarology*, 63(4), pp. 521–534. doi: 10.1007/s10493-014-9804-0.

Schuster, D. J. (1998) 'Intraplant distribution of immature lifestages of Bemisia argentifolii (Homoptera: Aleyrodidae) on tomato', *Environmental Entomology*, 27(1), pp. 1–9. doi: 00010009.

Silva, E. M. D. P. *et al.* (2019) 'Conventional Sampling Plan for Common Blossom Thrips, Frankliniella schultzei (Thysanoptera: Thripidae), in Bell Pepper', *Journal of Economic Entomology*, 112(3), pp. 1447–1453. doi: 10.1093/jee/toz037.

Simonne, A. H. *et al.* (1997) 'Ascorbic Acid and Provitamin A Contents in Unusually Colored Bell Peppers (Capsicum annuumL.)', *Journal of Food Composition and Analysis*, 10(4), pp. 299–311. doi: 10.1006/jfca.1997.0544.

Soares, J. R. S. *et al.* (2020) 'Spatiotemporal Dynamics and Natural Mortality Factors of Myzus persicae (Sulzer) (Hemiptera: Aphididae) in Bell Pepper Crops', *Neotropical Entomology*, 49(3), pp. 445–455. doi: 10.1007/s13744-020-00761-2.

Southwood, T. R. . (1978) 'Ecological Methods: with Particular Reference to Study of Insect Population.', *New York: Chapman and Hall*, p. 524.

Taylor, L. R. (1961) 'Aggregation, variance and the mean', *Nature*, 189(4766), pp. 732–735.
Weintraub, P. G. (2007) 'Integrated control of pests in tropical and subtropical sweet pepper production', *Pest management science*, 63, pp. 753–760. doi: 10.1002/ps.

Young, L. . and Young, J. . (1998) *Statistical ecology: a population perspective*. Boston,MA: Kluwer Academic Publishers.

Young, L. J. and Young, J. H. (1990) 'A spatial view of the negative binomial parameter k when describing insect populations', *In G. A. Milliken (ed.), Conference on Applied Statistics in Agriculture, Kansas State University, Manhattan, KS.*, p. 13–20.