Ciência Rural, Santa Maria, v.54:10, e20220094, 2024 http://doi.org/10.1590/0103-8478cr20220094

Ciência Rural

ISSNe 1678-4596
CROP PROTECTION

Mortality of *Tuta absoluta* by sprayers deposit volume structure

Gefferson Pereira da Paixão[1*] Marconi Ribeiro Furtado Júnior[1] Paulo Antônio Santana Júnior[2] Kleber Fialho de Arruda[1] Márcio Alexandre Moreira da Freitas[1]

[1]Departamento de Engenharia Agrícola, Universidade Federal de Viçosa (UFV), 36570-900, Viçosa, MG, Brasil. E-mail: gefferson.paixao@ufv.br.
[*]Corresponding author.
[2]Departamento de Entomologia, Universidade Federal de Viçosa (UFV), Viçosa, MG, Brasil.

ABSTRACT: In the scientific toxicity evaluations of insecticides against larvae of *Tuta absoluta* (Tomato pinworm), a leaf coverage rate of 100 % or very close to this value is sought to guarantee the contact of the insect with the chemical product. However, deposition can change according to the different pesticide application methods used in field productions; consequently, interfering with pest control. From this perspective, this study evaluated the mortality of *Tuta absoluta* and the deposited volume dispersion on tomato leaflets as a function of droplet sizes and the method of chemical treatment with abamectin. For that purpose, an experiment was conducted in a randomized block design with five treatments and five replications. The treatments consisted of different chemical treatment methods: immersion, hydraulic spraying with three droplet sizes, and pneumatic spraying, in which the following parameters were evaluated: larval mortality, volume retained (deposition), surface density of active ingredient, droplet density, and coverage percentage. The different chemical treatments with abamectin provided larval mortality rates above 90%. Furthermore, the highest mortality values (98% and 95.9%) were associated; respectively, with the sprayings that provided the highest droplet densities: hydraulic spraying with average droplets (181 droplets cm^{-2}) and pneumatic spraying with very fine droplets (256 droplets cm^{-2}), the latter using an application volume 84% lower (80 L ha^{-1}) than the lowest volume recommended by the manufacturer (500 L ha^{-1}).
Key words: deposition, *Tomato pinworm,* insecticide application, insecticide concentration, abamectin.

Mortalidade de *Tuta absoluta* em função da estrutura do volume depositado por pulverizadores

RESUMO: Nas avaliações de toxicidade de inseticidas às larvas de *Tuta absoluta* (Meyrick), procura-se obter 100 % ou próximo disso de cobertura foliar para garantir o contato do inseto com o produto testado. Entretanto, a deposição pode variar entre os diferentes métodos de aplicação empregados a nível de campo e, consequentemente, podem interferir no controle da praga. Objetivou-se com esse trabalho avaliar a mortalidade da *Tuta absoluta* e a dispersão do volume depositado em folíolos de tomate em função do tamanho de gotas e do método de tratamento químico com Abamectina. Para isso foi realizado um experimento no delineamento de blocos ao acaso com cinco tratamentos e cinco repetições. Os tratamentos foram constituídos por diferentes métodos de tratamento químico: imersão, pulverização hidráulica em três tamanhos de gotas, sendo cada tamanho de gota um tratamento, e pulverização pneumática em que foram avaliados: a mortalidade de larvas da espécie, o volume retido (deposição), a densidade superficial de ingrediente ativo, a densidade de gotas e a porcentagem de cobertura. Os diferentes métodos de tratamento químico com Abamectina proporcionaram mortalidade de larvas acima de 90% e, além disso, os maiores valores de mortalidade (98% e 95,9%) foram associados, respectivamente, às pulverizações que proporcionaram maiores densidades de gotas sendo elas: hidráulica com gotas médias (181 gotas cm^{-2}) e pneumática com gotas muito finas (256 gotas cm^{-2}), sendo esta última, utilizando um volume de aplicação 84% menor (80 L ha^{-1}) em relação ao menor volume recomendado pelo fabricante (500 L ha^{-1}).
Palavras-chave: deposição, traça do tomate, aplicação de inseticida, concentração de inseticida, abamectina.

INTRODUCTION

Due to the high destructive capacity of *Tuta absoluta* (tomato pinworm), this pathogen became one of the main pests that affect tomato plants (Lycopersicon esculentum Mill) (PICANÇO et al., 2007). In this scenario, even with the known efficacy of different insecticidal molecules used for its chemical control, several authors described this species as hard to control through spraying, especially due to the association of two factors: the diversified feeding habit of the pathogen, which favors its incidence throughout the entire crop cycle, and the plant architecture and high canopy density, which act as physical barriers by preventing the deposition of spray into the inner parts of the plant and areas more distant from the spraying nozzles (BIONDI et al., 2018; GUEDES et al., 2019).

Chemical treatment is the most used control method since it provides faster results and requires less effort during applications. However, the increased dependence on insecticides has increased the selection pressure of populations with resistance to several molecules, which is one of the main factors related to control failure likelihood (GUEDES & SIQUEIRA, 2012; SIQUEIRA et al., 2000; RODITAKIS et al., 2013). Among the different available compounds, the

Received 02.18.22 Approved 02.27.22 Returned by the author 05.13.24
CR-2022-0094.R1
Editors: Leandro Souza da Silva Uemerson Cunha

use of abamectin, which started in replacement to organophosphates and pyrethroids, has shown effectivity in several producing regions; although, mild resistance cases have already been reported in different continents (KONUŞ, 2014; SILVA et al., 2011; SIQUEIRA et al., 2001).

In the scientific methodology used to evaluate the susceptibility to pests and diseases, i.e., efficacy evaluations of chemical products, the aim is to guarantee 100% or very close to this value of chemical target coverage to guarantee the contact of the insect with the product (ex.: leaves immersed in solution) (IRAC, 2020). However, when field spraying is performed, the products applied as droplets are subject to losses and, even if the lethal concentration is deposited on the target, the volume and dispersion of deposited droplets may vary between sprayers and thus interfere with pest control (EBERT & DOWNER, 2006).

From this perspective, EBERT et al. (1999a,1999b) observed that the structure of the deposited volume, represented by the deposit size, the number per area, and the concentration of active ingredient per deposit play a key role in the toxic efficacy of any active ingredient. However, the variables should be studied together since they have a high degree of interdependence. When evaluated independently, there may be little transferability to the farming, complicating the identification of an effective minimum concentration.

Conversely, in studies addressing the application efficiency of sprayers, it is common for the evaluated parameters to focus on the droplet size spectrum and the volume applied. However; although, these factors directly influence the structure of the deposited volume, studies relating the characteristics of the spectrum to the minimum lethal concentration, pest control efficacy, and the biological behavior against the different concentrations of the droplets deposited are still rare. From this perspective, this study evaluated the association between the mortality of *Tuta absoluta* and the dispersion of the volume deposited on tomato leaflets as a function of droplet sizes and methods of chemical treatment with abamectin.

MATERIALS AND METHODS

Characterization of the population of Tuta absoluta and the insecticide

Before the assay was performed, the population of *Tuta absoluta* was characterized according to insecticide susceptibility by a resistance bioassay as described by CARVALHO (2017). We used in the assay the neurotoxic insecticide Abamectin (Vertimec® EC 18 g L^{-1}) (SYNGENTA, 2021) and a population of *Tuta absoluta* from the region of Viçosa (MG) already established at the Laboratory of Integrated Pest Management of Universidade Federal de Viçosa (UFV). It was thus possible to obtain the lethal concentrations (LC) of active ingredient for 50 and 80% mortality of the pest population (LC50 and LC80) and the slope value of the adjusted curve.

For the bioassay, tomato (cv. Santa Clara) leaflets were immersed in a solution containing water, insecticide, bright blue food coloring (3000 mg L^{-1}), and mineral oil (0.25% v/v); subsequently, the corrected mortalities were determined according to ABBOTT (1925). Six concentrations of active ingredient (a.i.) (increasing values) were utilized, with 6 replications and 10 to 12 2nd instar larvae each.

Then, the mortality data were submitted to Probit analysis (FINNEY, 1952), through the software R (R CORE TEAM, 2021) with the packages ExpDes.pt (R package version 1.2.2, 2021) (FERREIRA et al., 2021) and Ecotoxicology (R package version 1.0.1, 2015) (GAMA, 2015).

Critical control level (LSD80)

The critical control level for the pest population was determined through the Critical Lethal Surface Density (LSD80). This variable relates the mass of active ingredient per leaf surface area necessary to control 80% of the individuals in the population and was expressed as nanograms of a.i. per square centimeter (ng cm^{-2} of a.i.). The LSD80 was determined using the equation LSD80= DEP*THlowLC80, where DEP corresponds to the actual deposition value, i.e., the solution volume retained on the leaf surface after immersion, and THlowLC80 corresponds to the lower threshold of the fiducial interval of LC80 determined in the bioassay described in item 2.1. The LC80 was adopted as the critical pest control concentration since this is the minimum mortality required to register a pest control insecticide with the Ministry of Agriculture, Livestock, and Supply of Brazil (SILVA et al., 2011).

The mean DEP value used to calculate the LSD80 was obtained through the leaflet immersion method. Five tomato leaflets were used in this step, one for each replicate, and were immersed in a solution containing water, insecticide (commercial product in a dose of 1 mL L^{-1}), bright blue food coloring (3000 mg L^{-1}), and mineral oil (0.25 % v/v). After immersion and drying, the leaflets were put in plastic bags, and washed with 20 mL of distilled water in each bag, and the absorbances of the washing solution were determined in a spectrophotometer. After washing, the area of the leaflets was measured using a leaf area meter (LI-3100C Area Meter by Li-Cor®), and the deposition per unit of area (µL cm^{-2}) was determined according to PALLADINI (2005), obtaining a mean value of 5.03 µL cm^{-2}, i.e, it corresponds to the maximum volume of solution retained per area of leaflets.

Evaluation of mortality and deposited volume

The droplet spectrum was characterized before the assay for the hydraulic and pneumatic spray methods. In the laboratory, measured the variables of Volume Median Diameter (VMD), the percentage of droplets smaller than 100 µm (% < 100µm), and the SPAN index using a particle size analyzer (Spraytech, Malvern Instruments Co®). The VMD was used as a reference to classify the droplet spectrum according to the recommendations for applying agricultural products contained in regulation No. S-572 of the American Society of Agricultural and Biological Engineers (ASABE, 2011).

The assay was conducted in December 2020 at the Agricultural Mechanization Laboratory (AML) of the Department of Agricultural Engineering of the UFV in Viçosa - MG. The sprayers were fixed to a metal structure driven by a motor coupled to a 12 m-long hanging rack rail system at a constant speed (Figure 1A). The speed was adjusted with a frequency inverter, and the sprayer was triggered by a switch connected to a solenoid valve, in the case of the hydraulic sprayer, and to the engine ignition system of the pneumatic sprayer.

To determine the variables using the hydraulic sprayer, the sample units were placed under the structure at a distance of 0.5 m from the spraying nozzle (Figure 1B). For pneumatic spraying, the samples were placed transverse to the nozzle of the atomizer, forming an angle of approximately 45º at 1.5 m from the target, which was vertically positioned (Figure 1C). The sample units were fixed with pins on a polystyrene base which, in turn, was fixed to a wooden tray.

The assay was conducted in a closed environment at a mean temperature of 22.3 ºC and air relative humidity of 79.5%. Then, the sample units received a solution containing water, Abamectin insecticide, 3000 mg L^{-1} bright blue food coloring (used as a tracer to quantify the volume retained), and 0.25 % mineral oil (v/v). The active ingredient concentration in the solution was corrected according to the spray volume to apply 9 g ha^{-1} of a.i., the minimum recommended by the manufacturer, or the equivalent to 500 L ha^{-1} of spray volume in the standard concentration (18 mg of a.i. per Liter of water).

Hydraulic spraying

Hidraulic spraying was performed using a Herbicat® sprayer pressurized by CO2 and equipped with an aluminum cylinder with a capacity of 2 kg of gas, a 2L spray reservoir, pressure regulator, manometer, and a lance containing one spraying nozzle. The sprayer was regulated and equipped to produce three droplet sizes: fine (100-175 µm), medium (176-250 µm), and coarse (251-375 µm), and a spray volume of 300 L ha^{-1} of solution at the concentration 30 mg L^{-1} of a.i.. These parameters were achieved using the spray nozzles XR11002, LD11002, and AIXR110015 at respective pressures (200, 250, and 330 kPa), flow H rates (1.68, 2.18, and 0.625 L min^{-1}), and travel speeds (0.69, 0.83 and 0.69 m s^{-1}).

Pneumatic spraying

The pneumatic sprayer was developed by Guarany® and had a spray reservoir with a capacity

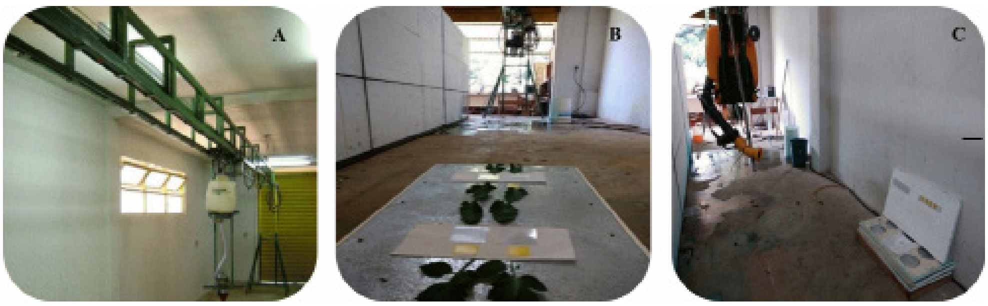

Figure 1 - Rail structure used to move the sprayers (A) and positioning of the sample units used for hydraulic (B) and pneumatic sprayers (C). Source: (A) Quirino, 2010. (B) and (C) the authors.

of 18 L and one white nozzle. The equipment was calibrated to produce a spray volume of 80 L ha^{-1} of solution with the a.i. concentration of 112.5 mg L^{-1}, a travel speed of 0.75 m s^{-1}, and a flow rate of 0.18 L min^{-1}.

Immersion method

For chemical treatment using the leaflet immersion method, a 0.5 L disposable container was used with the a.i. concentration of 18 mg L^{-1} in the solution.

Experimental design and variables

The experiment was conducted in a randomized block design with five treatments and five replications, with treatments consisting of five chemical treatment methods: immersion, hydraulic spraying in three droplet sizes (fine, medium, and coarse), and pneumatic spraying. The variables mortality (%), deposition (µL cm^{-2}), surface density (ng cm-2 of a.i.), droplet density (droplets cm^{-2}), and coverage percentage (%) were measured at this stage. However, the last two variables were not measured for the leaflet immersion method, and; therefore, the analyses were conducted with four treatments and five replications.

Tomato leaflets composed the sample units used to measure mortality. After chemical treatment and drying, 10 to 12 of the second instar larvae were transferred to the surface of each leaflet, and the mortality evaluations were performed 48 hours after this transference by considering as dead the insects that did not move. Finally, the mortality values of the treatments were corrected according to the control, as proposed by ABBOTT (1925).

To measure the deposition, the sample unit consisted of a PVC (Polyvinyl chloride) card with a known area (25 cm^{-2}). After chemical treatment and drying, the material was placed in plastic bags, washed by adding 20 mL of distilled water to each bag, and then the absorbances of the washing solution were determined with a spectrophotometer, thus determining the deposition per unit area (µL cm^{-2}) according to Palladini (2005). Subsequently, the deposition values were converted to surface density (SD), in ng cm^{-2} of a.i., according to the equation SD = Dep*ACS, where Dep corresponds to the actual deposition calculated after spraying, and ACS corresponds to the a.i. concentration in the solution (variable according to spray volume).

Finally, the droplet density and the coverage percentage were measured by attaching water-sensitive paper tags to each sampling point. After spraying, these tags were digitalized at 600 dpi resolution and analyzed with the software Gotas® (EMBRAPA, 2000), specifically developed to analyze water-sensitive tags.

Subsequently, the data were subjected to analysis of variance, and, in the case of significance, the means were compared by the Duncan test at 5 % probability using the statistical software Assistat, version 7.7 pt..

RESULTS AND DISCUSSION

Characterization of the population of Tuta absoluta and the insecticide

Table 1 shows the data on the relative toxicity of abamectin against the population of *Tuta absoluta*. However, according to the lower threshold of the LC80 (0.64 ng µL^{-1}) and the mean deposition of the solution on the leaflets (5.03 µL cm^{-2}), the LSD80 obtained corresponded to 3.21 ng cm-2 of a.i., which is the critical control level.

The abamectin concentration necessary to control 50 and 80% of the population was approximately 33 and 26 times lower than the concentration values recommended by the manufacturer, highlighting the high susceptibility of this population to abamectin. Furthermore, the proximity between these values demonstrated the low variability between the individuals of the population since a slight increase in the concentration of active ingredient resulted in an expressive increase in mortality from 50 to 80%.

These results agreed with the slope value adjusted by the Probit model. In several studies, the slope is used to evaluate the susceptibility of individuals of the same population to the active ingredient: the higher the value, the higher the predominance of a genotype in this population, denoting greater response homogeneity in the presence of insecticides (SIQUEIRA et al., 2000; SILVA et al., 2011). It should be noted that the slope adjusted for the population of the present study was superior to those observed in the studies mentioned before.

The low genetic variability of this population is due to its origin and maintenance in the laboratory for an extended period with no exposure to insecticides. Therefore, the selection of individuals with resistant or tolerant genes is, in a way, made unfeasible.

Characterization of the droplet spectrum

Among the droplet size classes in hydraulic spraying, the risk of drift decreased with the increase in the VMD, as observed when evaluating the change from

Table 1 - Abamectin toxicity to larvae of *Tuta absoluta* as a function of the LC_{50}, LC_{80} and the slope of the estimated model.

Population	--------N--------	--Slope ± SE----	--LC_{50} ($FI_{95\%}$)--	--LC $_{80}$ ($FI_{95\%}$)--	--------χ2---------	-----P-value-----
Region			ng μL^{-1} of a.i.	ng μL^{-1} of a.i.		
Viçosa-MG	395	8.05 ± 1.01	0.54 (0.51-0.57)	0.68 (0.64-0.76)	7.22	0.8753

N: Total number of larvae, SE: Standard Error, LC_{50}: Lethal concentration to control 50% of the population, LC_{80}: Lethal concentration to control 80% of the population, FI: Fiducial Interval. χ^2: Pearson's Chi-square.

fine to coarse sizes, with a reduction in the % < 100 µm (Table 2). However, higher VMD values tend to decrease droplet density and the percentage of covered area for the same spray volume (FERGUSON et al., 2016a).

In the characterization with the pneumatic sprayer, the droplet spectrum produced by the white nozzle was classified as very fine (Table 2). However; although, these are different liquid fractionation principles, the increase in the risk of drift due to high values of droplets with % < 100 µm in relation to the spectrum produced by hydraulic nozzles is highlighted.

The span values are presented for both evaluations, characterizing the homogeneity of the droplets produced. The closer to zero, the greater the spectrum homogeneity. Therefore, the coarse droplet spectrum in hydraulic spraying was more homogeneous, with values close to those found for pneumatic spraying.

Evaluation of mortality and deposited volume

In the mortality analysis of *Tuta absoluta* treated with abamectin, there was a significant difference between the different spraying methods, as seen in table 3. Regarding the leaf immersion method, only the treatments with hydraulic spraying using fine and coarse droplets differed statistically and caused less mortality in the evaluated population (Figure 2). This difference was also observed between the different droplet sizes evaluated as spraying with coarse droplets was less efficient. However, despite the differences observed, all treatments, regardless of their method and droplet size, caused more than 80% mortality and were satisfactory according to the criterion established by MAPA to be considered an effective control (Figure 2), also agreeing with Silva (2011) when using the leaf immersion method to evaluate the toxicity of abamectin against different populations of *Tuta absoluta*.

Table 2 - Characterization of the droplet spectrum as a function of different sprayers and droplet sizes.

Sprayer	Droplet size class	Spray Volume (L ha^{-1})	VMD (µm)	% < 100µm	Span
	Fine	300	173	15.53	1.90
HYDRAULIC	Medium	300	215	10.44	1.95
	Coarse	300	303	6.69	1.83
PNEUMATIC	Very Fine	80	94	53.44	1.78

VMD: Volume Median Diameter, % < 100µm: Percentage of droplets smaller than 100 µm, Span: Homogeneity coefficient.

Although, the mentioned criterion was considered satisfactory, it was possible to observe some associations between the biological behavior of the species against the parameters related to the leaf treatment methods. In this scenario, for the deposition, surface density, droplet density, and coverage percentage variables, there was a significant effect between the spraying methods employed, as seen in table 4.

In quantitative terms, the combination between volume reduction and concentration correction efficiently controlled the larvae and had little influence on mortality. As shown in figure 3A, the deposition provided by the immersion method was 19 times greater than the pneumatic spraying and three times greater than hydraulic spraying using medium

Table 3 - Summary of the analysis of variance for the corrected mortality of *Tuta absoluta* as a function of different chemical treatment methods.

FV	------------------------DF------------------------	----------------------Mean Square--------------------
		Corrected Mortality
Block	4	5.41^{ns}
Treatment	4	64.94^{*}
Residual	16	15.48
CV(%)	4.11	

FV: factor of variation, DF: degrees of freedom, CV: coefficient of variation. *Significant at 5 % probability, ns: non-significant by the F-test.

droplets. Therefore, according to the concentration used at each application, the surface density was increased by 3 and 1.8 times, respectively (Figure 3B). However, despite the difference in the retained volume, there was no difference between the mortalities provided by the mentioned methods (Figure 2).

Therefore, it can be inferred that the biological behavior of this population of *Tuta absoluta* was relatively neutral about the retained concentration of active ingredient since, due to the correction, the spraying with the lowest volumes resulted in more concentrated droplets. This finding reduces the evidence of behavioral resistance, as reported by MARTINI (2012), which is associated with the decreased mortality of a species due to repellence and avoidance of contact with the active ingredient, especially at high concentrations. In that study, the authors concluded that the chemical control of the carmine spider mite (*Tetranychus cinnabarinus*), a highly motile species, did not require high coverage rates when a non-repellent active ingredient was used, contrary to the more repellent product, which, combined with a low coverage percentage, was interpreted as the cause of the inferior performance in the incidence of the species.

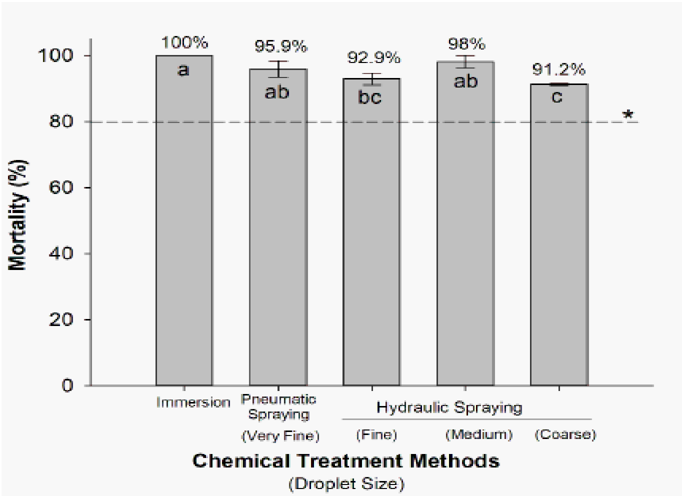

Figure 2 - Mean values observed for the mortality provided by different treatment methods and droplet sizes in the chemical control of Tuta absoluta. Means with equal letters between bars do not differ by the Duncan test at 5 % probability.
*Criterion e established by the Ministério da Agricultura, Pecuária e Abastecimento (MAPA) of Brazil in order to be considered an effective control.

When evaluating the dispersal of the retained volume provided by the sprayers, the previous statements corroborate the coverage percentage values directly related to the deposition behavior. However, the superiority of the coverage values in the leaf

Table 4 - Summary of the analysis of variance for the deposition, surface density, droplet density, and coverage percentage variables as a function of different chemical control methods against the population of *Tuta absoluta.*

FV	--------DF--------	------Mean Square------	
		Deposition	Surface Density
Block	4	0.29^{ns}	131.25^{ns}
Treatment	4	16.40^{**}	2881.51^{**}
Residual	16	0.24	95.69
CV(%)		25.09	19.24
FV	DF	Droplet Density	Coverage Percentage
Block	4	180.41^{ns}	0.78^{ns}
Treatment	3	26408.47^{**}	999.80^{**}
Residual	12	324.37	2.82
CV(%)		10.87	4.86

FV: factor of variation, DF: degrees of freedom, CV: coefficient of variation. **Significant at 1 % probability, ns: non-significant by the F-test.

immersion method (100 %) in relation to pneumatic spraying with very fine droplets and hydraulic spraying with average droplets corresponded to 6.76 and 2.16 times, respectively (Figure 4B).

Conversely, it was possible to establish a positive association between the differences in the mortality rates and droplet densities, i.e., the treatments whose spraying showed the highest mortality rates and were equivalent to the immersion method (pneumatic spraying with very fine droplets and hydraulic spraying with average droplets) were accompanied by the highest droplet densities, which was also true for hydraulic spraying with fine and coarse droplets (Figure 4A), the latter showing the lowest mortality values compared to the leaf immersion method (Figure 2).

These results demonstrated that the better the distribution of the volume retained on the leaf surface provided by spraying, the better the response on the mortality of *Tuta absoluta* if the deposited concentration provides a surface density of active ingredient higher than the minimum of 80% necessary to control the evaluated population, in this case, 3.21 ng cm-2 of a.i. These findings agreed with the evaluations conducted by SALLOUM (2019) as the higher control efficacy of *Tuta absoluta* was associated with sprayers that produced very fine droplets and higher densities compared to the sprayer

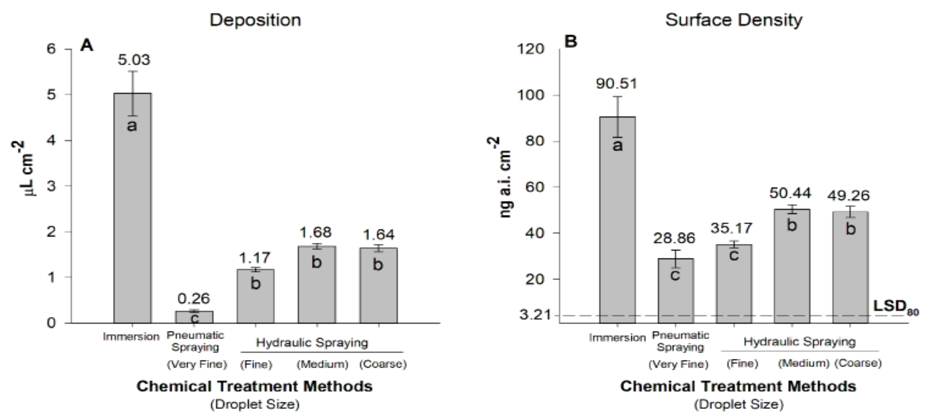

Figure 3 - Mean values observed for the deposition (A) and surface density (B) variables provided by the different treatments and droplet sizes in the chemical control of *Tuta absoluta*. Means with equal letters between bars for each variable do not differ by the Duncan test at 5 % probability. a.i.: active ingredient; LSD_{80}: critical lethal surface density value.

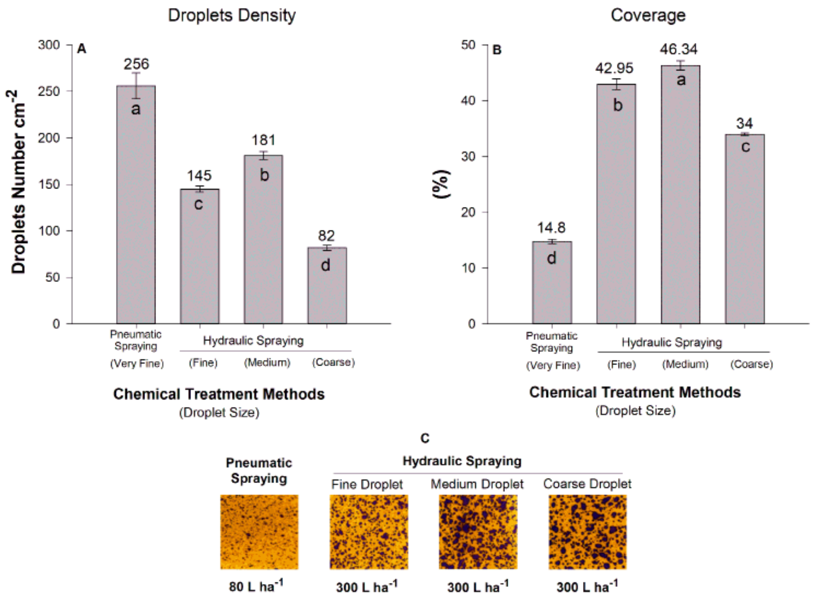

Figure 4 - Mean values of droplet density (A) coverage percentage (B), and water-sensitive tags (C) provided by the different treatments and droplet sizes in the chemical control of *Tuta absoluta*. Means with equal letters between bars for each variable do not differ by the Duncan test at 5% probability.

that produced coarse droplets and showed the lowest droplet density.

Regarding the droplet spectrum produced by the sprayers, it is well-established that the smaller the droplets, the greater the impact densities, and coverage for a constant volume (COURSHEE, 1967). However, the greater are also the risks of losses through evaporation and drift, which may result in volume reductions. Conversely, the lower risk of drift with coarser droplets can result in less canopy penetration (FERGUSON et al., 2016a, 2016b). This behavior was evident in the evaluation of the hydraulic sprayings in which coarse droplets resulted in lower droplet density and coverage values, followed by fine droplets, whose spectrum resulted in a higher risk of drift with higher values of droplets smaller than 100 µm.

The highest droplet densities obtained with pneumatic spraying are attributed to the high-pressure air flow produced by the equipment, which, in addition to fractioning the liquid into very fine droplets, assists in transporting the droplets to the target (SASAKI et al., 2013). These characteristics explain the superiority in relation to hydraulic spraying even if resulting in a spectrum with a higher risk of drift due to the higher percentage of droplets smaller than 100 µm.

Therefore; although, the droplet size variations and the type of sprayer did not influence the efficacy of the product against the population of *Tuta absoluta* with abamectin according to the 80% criterion, it was possible to understand better the effects of spraying parameters on the biological behavior of the species. It should also be noted that the concentration correction was efficient and should be performed to provide the minimum surface required by the population; therefore, the predominant resistance level of this population should be considered in relation to the active ingredient employed. However, this correction should be performed according to the volume applied and should not surpass the maximum limit established by the manufacturer, which was 21.6 g of abamectin per hectare in this study.

Furthermore, the greater control efficacy of this population of *Tuta absoluta* was associated with the highest droplet densities and, therefore, the treatments using the pneumatic sprayer with very fine droplets and the hydraulic sprayer with average droplets were the most effective. The viability of using lower application volumes than the recommended aims at reducing operational costs due to greater operational agility. However, this adaptation results in less deposited volume at a higher concentration of active ingredient, which may negatively influence non-targeted organisms (BARROS et al., 2015; PEREIRA et al., 2014). Finally, we stress that the evaluations were performed under controlled conditions and not considering the plant architecture and foliar density. Therefore, new studies should be conducted to continue observations under field conditions.

CONCLUSION

The different chemical treatment methods with abamectin provided larval mortality rates above 90% and were considered effective in controlling a population of *Tuta absoluta* from the region of Viçosa-MG, according to the criterion established by the Ministry of Agriculture, Livestock, and Supply of Brazil. Furthermore, all treatments provided a surface density deposition of active ingredient above the minimum density required to control 80% of the population.

The most effective chemical treatments for the mortality of this population of *Tuta absoluta* were pneumatic spraying with very fine droplets and hydraulic spraying with average droplets. Furthermore, the control of this species was directly associated with the higher droplet densities provided by these treatments.

The use of pneumatic spraying with very fine droplets, in addition to being efficient, provided the highest reduction in applied volume (80 L ha-1) compared to the lowest volume recommended by the manufacturer (500 L ha-1), i.e., a reduction of 84 %.

ACKNOWLEDGEMENTS

The authors thank the Department and the Agricultural Engineering Post-graduation - Universidade Federal de Viçosa (UFV), the Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq, and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) - Código Financeiro 001 for the financial support.

DECLARATION OF CONFLICT OF INTEREST

We have no conflict of interest to declare.

AUTHORS' CONTRIBUTION

All authors contributed in a similar way to write this manuscript, critically reviewed, and approved the final version.

REFERENCES

ABBOTT, W. S. A method of computing the effectiveness of an insecticide. **Journal of Economic Entomology**, v.18, p.265-267, 1925. Available from: <https://doi.org/10.1093/jee/18.2.265a>. Accessed: Mar. 22, 2024. doi: 10.1080/03601234.2015.965621.

AMERICAN SOCIETY OF AGRICULTURAL AND BIOLOGICAL ENGINEERS. **ASABE Standard S-572**: Spray nozzle classification by droplet spectra. St. Joseph, Michigan, 2011.

BARROS, E. C. et al. Physiological selectivity and activity reduction of insecticides by rainfall to predatory wasps of *Tuta absoluta*. **Journal of Environmental Science and Health, Part B**, v.50, p.45-54, 2015. Available from: <https://doi.org/10.1080/03601234.2015.965621>. Accessed: Mar. 22, 2021. doi: 10.1080/03601234.2015.965621.

BIONDI, A. et al. Ecology, worldwide spread, and management of the invasive South American tomato pinworm, *Tuta absoluta:* past, present, and future. **Annual Review of Entomology**, v.63, p.239-258, 2018. Available from: <https://doi.org/10.1146/annurev-ento-031616-034933>. Accessed: Jun. 15, 2020. doi: 10.1146/annurev-ento-031616-034933.

CARVALHO, J. R. et al. **Análise de probit aplicada a bioensaios com insetos**. Colatina: IFES, p.102, 2017.

COURSHEE, R. J. Application and use of foliar fungicides. In: TORGESON, D.C. (ed.) **Fungicide: An advanced treatise**. New York: Academic Press, p.239-286, 1967.

EBERT, T. A. et al. Deposit structure and efficacy of pesticide application. 2: Trichoplusia ni control on cabbage with fipronil. **Pesticide Science**, v.55, p.793-798, 1999b. Available from: <https://doi.org/10.1002/(SICI)1096-9063(199908)55:8<793::AID-PS14>3.0.CO;2-0>. Accessed: Feb. 9, 2020. doi: 10.1002/(SICI)1096-9063(199908)55:8<793::AID-PS14>3.0.CO;2-0.

EBERT, T. A.; DOWNER, R. A. A different look at experiments on pesticide distribution. **Crop Protection**, v.25, p.299-309, 2006. Available from: https://doi.org/10.1016/j.cropro.2005.06.002. Accessed: Feb. 11, 2020. doi: 10.1016/j.cropro.2005.06.002.

EBERT, T. A. et al. Deposit structure and efficacy of pesticide application. 1: Interactions between deposit size, toxicant concentration and deposit number. **Pesticide Science**, v.55, p.783-792, 1999a. Available from: <https://doi.org/10.1002/(SICI)1096-9063(199908)55:8<783::AID-PS973>3.0.CO;2-D>. Accessed: Feb. 11, 2020. doi: 10.1002/(SICI)1096-9063(199908)55:8<783::AID-PS973>3.0.CO;2-D.

EMBRAPA MEIO AMBIENTE: **GOTAS - Programa de calibração de pulverização**. Jaguariúna, 2000. Online. Available from: <https://www.embrapa.br/busca-de-solucoes-tecnologicas/-/produto-servico/1421/gotas---programa-de-calibracao-de-pulverizacao---gotas>.

FERGUSON, J. C. et al. Assessing the deposition and canopy penetration of nozzles with different spray qualities in an oat (*Avena sativa L.*) canopy. **Crop Protection**, v.81, p.14-19, 2016a. Available from: <https://doi.org/10.1016/j.cropro.2015.11.013>. Accessed: Jul. 03, 2020. doi: 0.1016/j.cropro.2015.11.013.

FERGUSON, J. C. et al. Pressure, droplet size classification, and nozzle arrangement effects on coverage and droplet number density using air-inclusion dual fan nozzles for pesticide applications. **Crop Protection**, v.89, p.231-238, 2016b. Available from: <https://doi.org/10.1016/j.cropro.2016.07.032>. Accessed: Jul. 3, 2020. doi: 10.1016/j.cropro.2016.07.032.

FERREIRA, E. B. et al. **ExpDes.pt: Experimental Designs package (Portuguese)**, R package version 1.2.2, 2021. Available from: <http://cran.ma.ic.ac.uk/web/packages/ExpDes.pt/ExpDes.pt.pdf>. Accessed: Jan. 17, 2022

FINNEY, D. J. **Probit analysis**: a statistical treatment of the sigmoid response curve. Cambridge: Univ. Press, 1952.

GAMA, J. **Ecotoxicology**: methods for ecotoxicology. R package version 1.0.1, 2015. Available from: <https://cran.r-project.org/web/packages/ecotoxicology/ecotoxicology.pdf>. Accessed: Sept. 17, 2020

GUEDES, R. N. C. et al. Insecticide resistance in the tomato pinworm ***Tuta absoluta***: patterns, spread, mechanisms, management and outlook. **Journal of Pest Science**, v.92, p.1329–1342, 2019. Available from: <https://doi.org/10.1007/s10340-019-01086-9>. Accessed: Sept. 17, 2020. doi: 10.1007/s10340-019-01086-9.

GUEDES, R. N. C. SIQUEIRA, H. A. A. The tomato borer *Tuta absoluta*: insecticide resistance and control failure. **CAB Reviews**, v.7, p.1-7, 2012. Available from: <https://www.cabdirect.org/cabdirect/FullTextPDF/2012/20123334742.pdf>. Accessed: Sept. 29, 2020. doi: 10.1079/PAVSNNR20127055.

IRAC - INSECTICIDE RESISTANCE ACTION COMMITTEE**. IRAC Method nº 22: Susceptibility Test Methods of *Tuta absoluta***, version 3, 2020. Available from: <https://irac-online.org/content/uploads/Method_022_Tuta.pdf>.

KONUŞ, M. Analysing resistance of different T. absoluta (Meyrick) (Lepidoptera: Gelechiidae) strains to abamectin insecticide. **Turkish Journal Biochemistry**, v.39, p.291-297, 2014. Available from: <https://jag.journalagent.com/z4/download_fulltext.asp?pdir=tjb&plng=eng&un=TJB-09327>. Accessed: Mar. 21, 2021 doi: 10.5505/tjb.2014.09327.

MARTINI, X. et al. Quantitative impact assessment of spray coverage and pest behavior on contact pesticide performance. **Pest management science**, v.68, n.11, p.1471-1477, 2012. Available from: <https://doi.org/10.1002/ps.3330>. Accessed: Jan. 13, 2021. doi: 10.1002/ps.3330.

PALLADINI, L. A. et al. Choice of tracers for the evaluation of spray deposits. **Scientia Agricola**, v. 62, p. 440-445, 2005. Available from: <https://www.scielo.br/j/sa/a/jcGkxrbmtWJkSJVWndxWbYr/?format=pdf&lang=en>. Accessed: Apr. 9, 2018. doi:10.1590/S0103-90162005000500005.

PEREIRA, R. R. et al. Insecticide toxicity and walking response of three pirate bug predators of the tomato leaf miner ***Tuta absoluta*. Agricultural and Forest Entomology**, v.16, n.3, p.293-301, 2014. Available from: <https://doi.org/10.1111/afe.12059>. Accessed: Mar. 11, 2021. doi: 10.1111/afe.12059.

PICANÇO, M. C. et al. Effect of integrated pest management practices on tomato production and conservation of natural enemies. **Agricultural and Forest Entomology**, v.9, p.327 – 335, 2007. Available from: <https://doi.org/10.1111/j.1461-9563.2007.00346.x>. Accessed: Sept. 28, 2020. doi: 10.1111/j.1461-9563.2007.00346.x.

QUIRINO, A. L. S. **Parâmetros técnicos para a aplicação do glyphosate visando o aumento da eficácia segurança ambiental e do aplicador**. p.61, 2010. Dissertação (Mestrado em Engenharia Agrícola) – Curso de Pós-graduação em Engenharia Agrícola, Universidade Federal de Viçosa. Available from: <https://www.locus.ufv.br/bitstream/123456789/3570/1/texto%20completo.pdf>. Accessed: Jul. 13, 2020.

R CORE TEAM. R: **A language and environment for statistical computing**. R Foundation for Statistical Computing, Vienna, Austria, 2021. Available from: <https://www.R-project.org/>. Accessed: Dec. 31, 2021.

RODITAKIS, E. et al. Toxicity of insecticides to populations of tomato borer *Tuta absoluta* (Meyrick) from Greece. **Pest management science**, v.69, p.834-840, 2013. Available from: <https://doi.org/10.1002/ps.3442>. Accessed: Sept. 28, 2020. doi: 10.1002/ps.3442.

SALLOUM, W. M. Effect of sprayer, nozzle types and spraying volume on efficacy of chemical compounds against tomato leafminer *Tuta absoluta* (Lepidoptera: Gelechiidae) infesting tomato. **Egyptian Journal of Plant Protection Research Institute**, v.2, p.247-255, 2019. Available from: <http://www.ejppri.eg.net/pdf/v2n2/7.pdf>. Accessed: Mar. 18, 2021.

SASAKI, R. S. et al. Deposição e uniformidade de distribuição da calda de aplicação em plantas de café utilizando a pulverização eletrostática. **Ciência Rural**, Santa Maria, v.43, n.9, p.1605-1609, 2013. Available from: <https://doi.org/10.1590/S0103-84782013000900011>. Accessed: Sept. 28, 2020. doi: 10.1590/S0103-84782013000900011.

SILVA, G. A. et al. Control failure likelihood and spatial dependence of insecticide resistance in the tomato pinworm, ***Tuta absoluta***. **Pest management science**, v.67, n.8, p.913-920, 2011. Available from: <https://doi.org/10.1002/ps.2131>. Accessed: Oct. 3, 2020. doi: 10.1002/ps.2131.

SIQUEIRA, H. A. A. et al. Abamectin resistance and synergism in Brazilian populations of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). **International Journal of Pest Management**, v.47, n.4, p.247-251, 2001. Available from: <https://doi.org/10.1080/09670870110044634>. Accessed: Oct. 03, 2020. doi: 10.1080/09670870110044634.

SIQUEIRA, H. A. A. et al. Insecticide resistance in populations of *Tuta absoluta* (Lepidoptera: Gelechiidae). **Agricultural and Forest Entomology**, v.2, n.2, p.147-153, 2000. Available from: <https://doi.org/10.1046/j.1461-9563.2000.00062.x>. Accessed: Nov. 09, 2020. doi: 10.1046/j.1461-9563.2000.00062.x.

SYNGENTA PROTEÇÃO DE CULTIVOS LTDA. **Bula Vertimec® 18 EC**, 2021. Available from: <https://www.syngenta.com.br/sites/g/files/zhg256/f/vertimec_18_ec.pdf?token=1603808389>. Accessed: May, 14, 2021.