Influence of Rainfall and Drying Time on the Efficacy of Insecticides for the Control of *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae) in Apple Orchards

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Abstract

Field experiments were conducted to evaluate the effects of rainfall and drying time on the efficacy of two chemical insecticides used to control the oriental fruit moth (*Grapholita molesta*; Lepidoptera: Tortricidae) in apple orchards. The study was carried out at the Temperate Climate Fruit Experimental Station of the Brazilian Agricultural Research Corporation (Embrapa Uva e Vinho) in Vacaria, RS, Brazil, in a 0.4-hectare orchard with 7- and 8-year-old Gala and Fuji apple trees during the 2018/2019 and 2019/2020 production cycles. A Swanson-type rainfall simulator was employed to reproduce rainfall events under commercial orchard conditions. Simulated rainfall at intensities of 10 or 50 mm h^{-1} did not reduce the overall efficacy of insecticide control within 1 hour after precipitation. Notably, control efficacy increased during the first 30 minutes of rainfall, likely due to the redistribution of pesticides across plant surfaces. A drying period of 6 hours for both phosmet and chlorantraniliprole was sufficient to maintain insecticide performance, regardless of rainfall intensity. These findings provide practical guidance for apple growers, supporting informed decision-making regarding the optimal timing for insecticide reapplication under varying rainfall conditions.

Keywords: *Malus domestica*, phosmet, chlorantraniliprole, rain fastness, pests, chemical control

Influencia de la lluvia y del tiempo de secado sobre la eficacia de insecticidas para el control de *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae) en huertos de manzano

Resumen

Se realizaron experimentos de campo para evaluar los efectos de la lluvia y del tiempo de secado sobre la eficacia de dos insecticidas químicos utilizados para el control de la polilla oriental de la fruta (*Grapholita molesta*; Lepidoptera: Tortricidae) en huertos de manzano. El estudio se llevó a cabo en la Estación Experimental de Fruticultura de Clima Templado de la Empresa Brasileña de Investigación Agropecuaria (Embrapa Uva e Vinho), en Vacaria, RS, Brasil, en un huerto de 0,4 hectáreas con manzanos de 7 y 8 años de las variedades Gala y Fuji, durante los ciclos productivos 2018/2019 y 2019/2020. Se utilizó un simulador de lluvia tipo Swanson para reproducir eventos de precipitación bajo condiciones reales de producción. Las lluvias simuladas con intensidades de 10 o 50 mm h^{-1} no redujeron la eficacia general del control dentro de la primera hora después de la precipitación. De hecho, la eficacia aumentó durante los primeros 30 minutos de lluvia, probablemente debido a la redistribución de los insecticidas sobre las superficies de las plantas. Un período de secado de 6 horas para los insecticidas fosmet y clorantraniliprol fue suficiente para mantener su efectividad, independientemente de la intensidad de la lluvia. Estos resultados ofrecen información práctica para los productores de manzana y los ayudan a tomar decisiones informadas sobre el momento óptimo para la reaplicación de insecticidas bajo diferentes condiciones de precipitación.

Palabras clave: *Malus domestica*, phosmet, chlorantraniliprole, resistencia a la lluvia, plagas, control químico

Influência da chuva e do tempo de secagem sobre a eficiência de inseticidas no controle de *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae) em pomares de macieira

Resumo

Foram realizados experimentos de campo para avaliar os efeitos da chuva e do tempo de secagem sobre a eficácia de dois inseticidas químicos utilizados no controle da mariposa-oriental (*Grapholita molesta*; Lepidoptera: Tortricidae) em pomares de macieira. O estudo foi conduzido na Estação Experimental de Fruticultura de Clima Temperado da Empresa Brasileira de Pesquisa Agropecuária (Embrapa Uva e Vinho), em Vacaria, RS, Brasil, em um pomar de 0,4 hectare com macieiras de 7 e 8 anos das cultivares Gala e Fuji, durante os ciclos produtivos de 2018/2019 e 2019/2020. Um simulador de chuva do tipo Swanson foi utilizado para reproduzir eventos de precipitação em condições comerciais de produção. As chuvas simuladas, com intensidades de 10 ou 50 mm h^{-1}, não reduziram a eficácia geral do controle dentro da primeira hora após a precipitação. De forma notável, a eficácia do controle aumentou durante os primeiros 30 minutos de chuva, provavelmente devido à redistribuição dos pesticidas nas superfícies das plantas. Um período de secagem de 6 horas para os inseticidas fosmete e clorantraniliprole foi suficiente para manter seu desempenho, independentemente da intensidade da chuva. Esses resultados oferecem orientação prática aos produtores de maçã, apoiando a tomada de decisões informadas sobre o momento ideal para a reaplicação de inseticidas sob diferentes condições de precipitação.

Palavras-chave: *Malus domestica*, phosmet, chlorantraniliprole, resistência à chuva, pragas, controle químico

1. Introduction

The use of chemical control through pesticide applications is a common practice in apple production systems across southern Brazil (Wurz et al., 2019). Approximately 40 applications are required throughout the growing season (Faoro, 2022). The southern region of Brazil is the country's primary apple production hub, but it experiences insufficient winter chill and high rainfall volume and intensity (Nachtigall & Hawerroth, 2022). These factors have been identified as the primary drivers behind the frequent use of pesticides in apple production.

Although pesticides are used intensively in apple cultivation, their application is strictly controlled. Procedures, forms, and methods follow technical guidelines specific to apple growing. This ensures that the apples provided to consumers are safe and produced in line with environmental sustainability principles (Cruz et al., 2012). Consequently, Brazilian apples have stood out in global fruit production, reaching and maintaining demanding markets, such as those in Europe (Beling, 2018).

Established pest management programs advocate for initiating interventions upon detecting a specific threshold of target insects in monitoring traps or when their damage exceeds the maximum tolerable limit (Protas & Sanhueza, 2002). Although growers diligently follow technical application recommendations and adhere to maximum residue limits allowed in fruits, they are constantly challenged by the climate conditions of southern Brazil.

Weather conditions can greatly influence the success of phytosanitary management strategies (Baronio et al., 2023). For pest control to be effective, pesticides must adhere well to plant tissues and remain stable under varying climatic conditions (Katagi, 2004; Thacker & Young, 1999). Rainfall is a climate event that can negatively impact pesticide performance by dislodging pesticide deposits from plant surfaces, reducing the concentration of active ingredients in plant tissues, and consequently diminishing their efficacy (Taylor & Matthews, 1986).

Research has shown that pest control efficacy of pesticides reduces with increasing rainfall intensity due to the wash-off of applied active ingredients from plants (Hulbert et al., 2011). In the case of insecticides specifically, studies have indicated that the impact of rainfall on these products depends on several factors, including rainfall intensity, product drying time on the plant, affinity of product compounds to the leaf surface and penetration capacity into plant tissues (Andika et al., 2019; Wise et al., 2017). Additionally, each insecticide has distinct physicochemical properties –such as being more hydrophobic or hydrophilic– which influence its ability to remain on the plant or persist in the environment even after rainfall. Consequently, rainfall compromises pest protection levels and transports the product from the plant into the soil, thereby adversely affecting the environment (Casida & Quistad, 1998).

Vacaria, located in the northeastern region of the state of Rio Grande do Sul, Brazil, emerged as the largest apple-producing municipality in 2022, with a production area of 6,910.98 hectares, accounting for 48% of the state's total apple production area. Apple growers in the Vacaria region frequently experience heavy rainfall during the apple harvest season. According to Nachtigall and Hawerroth (2022), Vacaria had a mean monthly rainfall depth exceeding 200 mm from September to March between 1991 and 2019. This high rainfall index generates uncertainty for apple growers regarding the decision to reapply pesticides following a rainfall event in their orchards.

Unnecessary pesticide reapplications can lead to increased production costs and environmental hazards. Additionally, they may result in residues on fruits that exceed the maximum permissible limits, making them unsuitable for consumption and thus hindering both domestic and international market access. However, the lack of pesticide applications can leave orchards unprotected and susceptible to significant losses due to pest infestations.

The use of organophosphate insecticides, such as phosmet, is a widely adopted strategy among Brazilian apple growers for controlling the oriental fruit moth (*Grapholita molesta*; Lepidoptera: Tortricidae) in orchards (Arioli et al., 2017). Additionally, novel molecules, such as anthranilic diamides, including the active ingredient chlorantraniliprole, have also been utilized due to their high efficacy and low toxicity to mammals (Arioli et al., 2017; Lahm et al., 2007). However, the impact of rainfall on the field efficacy of this group of insecticides for controlling *G. molesta* larvae in apple trees remains unknown.

Establishing technical criteria that consider product drying time on the plant and rainfall intensity following application is essential for optimizing the chemical control of pests, guiding decisions on pesticide reapplications and

ensuring safety for the agricultural sector. In this context, the objective of the present study was to assess the efficacy of phosmet and chlorantraniliprole insecticides against *G. molesta* as a function of rainfall intensity and drying time of the molecules on apple trees.

2. Materials and Methods

The study was developed at the Temperate Climate Fruit Experimental Station of the Brazilian Agricultural Research Corporation (Embrapa Uva e Vinho) in Vacaria, RS, Brazil, within a 0.4-hectare apple orchard containing 7- and 8-year-old trees of the cultivars Gala and Fuji, in the 2018/2019 and 2019/2020 production cycles. The region's climate is classified as humid subtropical with temperate summers (Cfb), according to the Köppen-Geiger system (Alvares et al., 2013; Peel et al., 2007).

A Swanson-type rainfall simulator, adapted by Bertol et al. (2012), was employed to simulate rainfall in an apple orchard under production (Figure 1). The simulator comprises 30 sprinklers, with 1 to 3 nozzles open per sprinkler arm, arranged in a predefined pattern to simulate rainfall intensities of 50 and 10 mm h^{-1} during the first and second years of the study, respectively.

Figure 1. Overview of the Swanson-type rainfall simulator applying simulated rain to apple trees under field conditions, Vacaria, RS, Brazil, 2019

Source. Photographs by Daniela Fernanda Klesener.

The apple trees in the orchard were pruned to a height of 2 m (6.6 ft), and the simulator arms were positioned to rotate at 3.5 m (11.5 ft) above the ground, ensuring that the simulated rainfall was applied 1.5 m (4.9 ft) from the tree canopy. Forty-tree plots were established within the orchard, and the rainfall simulator was moved between these plots after each simulated rain event according to the treatment (rainfall intensity, insecticide molecule, and product drying time on the plant). Since only one simulator and one experimental area were available, insecticide applications were performed at different times. After each application, all corresponding tests were conducted before proceeding to the next molecule. To avoid cross-contamination between treatments, a minimum interval of 30 days was respected between applications, ensuring that the previously applied product was no longer active on the plants. Rainfall intensity was measured and calibrated using 20 plastic rain gauges with a capacity of 150 mm placed under the simulator during preliminary tests.

The control efficiency (%) of *G. molesta* larvae in fruits after the application of the insecticides phosmet (Imidan® at a rate of 200 g 100L^{-1}) and chlorantraniliprole (Altacor® at a rate of 10 g 100 L^{-1}) was used to assess the

effects of insecticide drying time on plants and rainfall intensity on insecticide molecules. Insecticides were sprayed on the trees at the fruiting stage, using an axial turbo atomizer set to a spray volume of 1,000 L ha^{-1}, following the technical recommendations for apple orchards.

Drying times were monitored after insecticide application, considering time intervals of 30 minutes, 2 hours, 6 hours, and 24 hours before the simulated rainfall events began. The 24-hour drying time was only used in the first year of the study, with a rainfall intensity of 50 mm h^{-1}. One-hour simulated rainfall events were conducted for each insecticide tested, with one simulated rainfall for each drying time.

Insecticide efficacy was determined by evaluating internal damage caused by *G. molesta* in apple fruits collected from branches located in the middle part of the trees, approximately 1.3 m (4.3 ft) above the ground. At each evaluation time –before simulated rainfall (control – 0 mm), and 5, 15, 30, and 60 minutes after the start of rainfall– five fruits were randomly collected per replication. Each replication corresponded to a different tree, and the experiment included four replications, totaling 100 fruits assessed per simulated rainfall event. All applications were carried out under typical field conditions during the apple production season, and the use of experimental replications ensured consistent and reliable results, particularly in the evaluation of drying times.

Treated fruits were collected and transported to a laboratory, where they were kept refrigerated until the end of the final simulated rainfall. Two first-instar larvae of *G. molesta* were carefully placed onto each fruit, specifically on the upper third of the fruit, near the peduncle, using a paintbrush, following the methodology described by Arioli et al. (2007). The larvae were obtained from a rearing colony maintained by the Entomology Laboratory at the Temperate Climate Fruit Experimental Station of Embrapa Uva e Vinho (Vacaria, RS). Each infested fruit was then individually placed into a plastic bag, which was sealed and maintained under controlled conditions (25 °C and a 16-hour photoperiod) for 10 days. Subsequently, all the fruits were dissected and evaluated for internal damage caused by the larvae.

The collected data were tabulated, and the variable analyzed was the percentage of fruit damage caused by *G. molesta*, corrected using Abbott's formula. Normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated using the Hartley and Bartlett tests. Data were transformed using the $(X+1)^{1/2}$ transformation prior to statistical analysis. The transformed data were subjected to analysis of variance (ANOVA), and treatment means were compared using Duncan's multiple range test at a 5% significance level. All statistical analyses were performed using the BioEstat statistical software package (Ayres et al., 2007). Additionally, mortality data for *G. molesta* larvae as a function of rainfall duration were plotted graphically, and trend curves were estimated for each active ingredient (insecticide) and tested rainfall intensity.

3. Results and Discussion

The results showed a general trend of increasing and then decreasing control efficacy against *G. molesta* as the rainfall duration on the plants increased, regardless of the applied pesticide (Figure 2). However, this trend changed with the insecticide drying time on the plant; as the time between insecticide application and the onset of rainfall event increased, the variations in control efficacy reduced (Figure 2). Additionally, the different rainfall intensities resulted in different control patterns. Simulated rainfall at an intensity of 50 mm h^{-1} resulted in a more rapid increase in insecticide control efficiency during the initial minutes of rainfall, whereas rainfall at an intensity of 10 mm h^{-1} showed a slower variation (Figure 2). Overall, the control efficacy of both tested insecticides showed an increasing curve, reaching a maximum control efficacy at approximately 30 minutes after the start of simulated rainfall, followed by a reduction in control until the completion of the final simulated rainfall event (Figure 2).
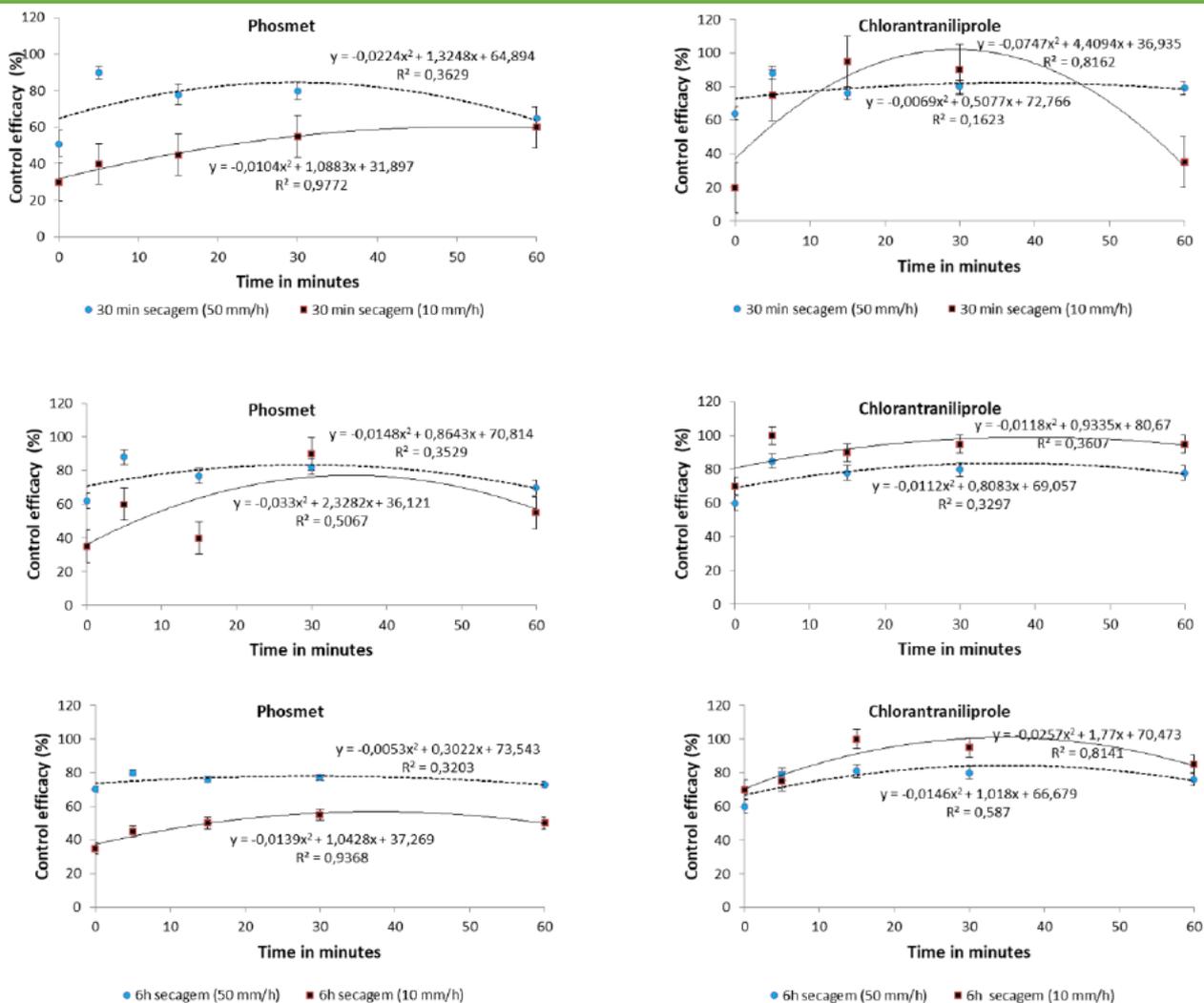
Figure 2. Mean control efficacy (mean ± standard error) against *Grapholita molesta* larvae by phosmet (Imidan®) and chlorantraniliprole (Altacor®) insecticides at three drying times (30 minutes, 2 hours, and 6 hours) after application to apple trees subjected to simulated rainfall at intensity of 50 or 10 mm h⁻¹, Vacaria, RS, Brazil

Trend curves were plotted based on the same data analyzed by ANOVA and Duncan's test at a 5% significance level.

Considering the phosmet insecticide, a significant increase in efficacy against *G. molesta* was observed at the onset of rainfall (50 mm h⁻¹) for drying times of 0.5 and 2 hours. Control efficacy increased from 51 ± 7.2% to 90 ± 3.4% and from 62 ± 12.1% to 88 ± 4.2% after five minutes of rainfall, with drying times of 30 minutes and 2 hours, respectively (Table 1).

The control efficacy found at the end of rainfall (60 minutes) did not differ significantly from that found before the onset of rainfall (Table 1). Drying times of 6 and 24 hours exhibited greater resistance to rainfall, as no significant differences in control percentages were found (Table 1). The rainfall intensity of 10 mm h⁻¹ showed a significant difference in insecticide control efficiency only for the 30-minute simulated rainfall and 2-hour drying time, which achieved 90 ± 6.9% control (Table 1). These results indicate that a 6-hour drying time for the phosmet insecticide was sufficient to prevent interference with control efficacy against of *G. molesta* in apple trees.

Wise et al. (2017) reported that phosmet is highly susceptible to wash-off by rainfall, particularly in apple trees; however, it did not affect the mortality of *Cydia pomonella* larvae (Lepidoptera: Tortricidae). According to Wise et al. (2015), the field-approved rate of phosmet can withstand 67% loss due to rainfall and still provide sufficient residues to maintain control efficacy. Additionally, phosmet can compensate for losses by rainfall through its contact action, allowing it to contaminate insects still moving on the fruit surface.

Table 1. Mean control efficiency (mean ± standard error) against *Grapholita molesta* larvae by phosmet (Imidan®) and chlorantraniliprole (Altacor®) insecticides as a function of product drying time on apple trees subjected to simulated rainfall events at intensity of 50- or 10-mm h^{-1}, Vacaria, RS, Brazil

Rainfall duration	Drying time on the plant (hours)			
	0.5	2	6	24
Phosmet - Rainfall at intensity of 50 mm				
0 min	51 ± 7.2 cA	62 ± 12.1 bA	70 ± 12.4 aA	69 ± 15.6 aA
05 min	90 ± 3.4 aA	88 ± 4.2 aA	80 ± 4.7 aA	84 ± 3.8 aA
15 min	78 ± 5.7 abA	77 ± 1.9 abA	76 ± 9.1 aA	87 ± 3.8 aA
30 min	80 ± 4.7 abA	82 ± 8.3 abA	77 ± 6.3 aA	80 ± 8.0 aA
60 min	65 ± 6.1 bcA	70 ± 3.3 abA	73 ± 6.7 aA	78 ± 7.8 aA
Chlorantraniliprole - Rainfall at intensity of 50 mm				
0 min	64 ± 4.3 bAB	60 ± 11.7 bB	60 ± 6.1 bB	84 ± 6.3 aA
05 min	88 ± 2.5 aA	85 ± 5.4 aA	79 ± 3.6 abA	76 ± 8.0 aA
15 min	76 ± 6.9 abA	78 ± 2.5 abA	81 ± 5.5 aA	81 ± 9.6 aA
30 min	80 ± 6.8 abA	80 ± 3.6 abA	80 ± 6.1 aA	90 ± 3.5 aA
60 min	79 ± 5.5 aBA	78 ± 3.7 aBA	76 ± 6.3 aBA	81 ± 5.9 aA
Phosmet - Rainfall at intensity of 10 mm				
0 min	30 ± 10.5 aA	35 ± 10.4 bA	35 ± 10.9 aA	-
05 min	40 ± 11.2 aA	60 ± 11.2 bA	45 ± 11.4 aA	-
15 min	45 ± 11.4 aA	40 ± 11.2 bA	50 ± 11.4 aA	-
30 min	55 ± 11.4 aB	90 ± 6.9 aA	55 ± 11.4 aB	-
60 min	60 ± 11.2 aA	55 ± 11.4 bA	50 ± 11.4 aA	-
Chlorantraniliprole - Rainfall at intensity of 10 mm				
0 min	20 ± 9.2 bB	70 ± 10.5 bA	70 ± 10.5 cA	-
05 min	75 ± 9.9 aB	100 ± 0.0 aA	75 ± 9.9 bcB	-
15 min	95 ± 5.0 aA	90 ± 6.9 aA	100 ± 0.0 aA	-
30 min	90 ± 6.9 aA	95 ± 5.0 aA	95 ± 5.0 abA	-
60 min	35 ± 10.9 bB	95 ± 5.0 aA	85 ± 8.2 abcA	-

Means followed by the same lowercase letter in the columns or uppercase letter in the rows are not significantly different from each other by analysis of variance (ANOVA) followed by Duncan's test at a 5% significance level.

The chlorantraniliprole insecticide also exhibited a significant increasing trend in its control efficacy after the onset of rainfall at both tested intensities (50 and 10 mm h^{-1}) for 0.5- and 2-hour drying times (Table 1). Regarding the rainfall intensity of 50 mm h^{-1}, control efficacy increased from 64 ± 4.3% to 88 ± 2.5% and from 60 ± 11.7% to 85 ± 5.4% for drying times of 30 minutes and 2 hours, respectively. Regarding the rainfall intensity of 10 mm h^{-1}, control efficacy increased from 20 ± 9.2% to 75 ± 9.9% and from 70 ± 10.5% to 100% for drying times of 30 minutes and 2 hours, respectively (Table 1). Control efficacy stabilized throughout the rainfall events on the apple trees, and a trend of returning to the initial control percentage were observed for the 10 mm h^{-1} rainfall intensity (Table 1), with no significant change in control efficacy for 6- and 24-hour drying times (Table 1). Therefore, the results denote the existence of a wash-off effect of the applied insecticides from the apple trees caused by rainfall, and that this effect is diminished over time as the insecticide dries on the plant.

The impact of rainfall on insecticide efficacy can vary depending on the insecticide's toxicity, persistence, penetration into plant tissues, and rainfall intensity (Hulbert et al., 2011, 2012). Systemic insecticides are less affected by rainfall than contact insecticides, which act on the surface of leaves and fruits and are therefore susceptible

to wash-off. Phosmet and chlorantraniliprole insecticides act by contact and ingestion on *G. molesta* and, despite not being systemic, they affect fruits, which may increase their resistance to rainfall. Wise et al. (2017) investigated the impact of rainfall on insecticide efficacy in apple trees; phosmet was classified as susceptible to wash-off by rainfall, mainly on fruits, with losses of 79% and 88% for 25.4- and 50.8-mm rainfall, respectively. In contrast, chlorantraniliprole showed resistance to rainfall, with a fruit loss of 13% for 25.4 mm rainfall. Considering these results, they reported that maintaining an effective control is only possible by using a rate higher than that approved for phosmet.

The observed increase in control efficacy during the initial minutes of rainfall may be related to the type of rainfall simulator used in this study, which allows for in-orchard testing without removing plant parts. By simulating rainfall directly on intact apple trees, the experimental conditions more closely resemble those found in the field. This setup enables the observation of product redistribution on the plant surface –a phenomenon that cannot be detected in studies using detached branches or fruits. In such studies, like those conducted by Wise et al. (2017) and Andika et al. (2019), the pesticide washed off by rainfall falls directly to the ground, preventing any redistribution effect from being assessed.

The observed insecticide redistribution can be attributed to several factors, including the type of spraying device, plant architecture, and environmental conditions. The axial turbo atomizer employed in this research is the most used device in the apple production sector in Brazil (Alves et al., 2013). It generates a large volume of air assistance and offers limited adjustment options. During the spraying operation, the device cannot be configured to target only the fruits, as the plant leaves have a larger surface area compared to the fruits. Therefore, the droplets do not reach the plant uniformly, and the fruits and leaves do not accumulate the same amounts of the products (An et al., 2022).

In this context, insecticide redistribution occurred on the apple trees during the initial stages of rainfall. Therefore, rainfall acts as a dispersal agent for pesticides, removing unabsorbed products from the plant surface and redistributing them to other parts, including fruits (Klesener et al., 2024). The peduncular region is the preferred entry site for *G. molesta* in apple fruits (Nava et al., 2014), consequently, a higher concentration of pesticide in this region improves the pest control efficacy. However, rainfall removes the pesticide from fruits over time and transports it to the soil, causing the control efficacy to return to original levels before the onset of rainfall (Figure 2). This indicates that rainfall duration exceeding one hour may negatively impact insecticide performance.

The results found in this study showed that a six-hour drying time is safe and sufficient to maintain control efficacy against *G. molesta* in apple trees for the tested insecticides. Apple growers in southern Brazil empirically believe that a four-hour drying time before rainfall is sufficient for pesticide absorption, regardless of the product used. The results obtained here support this notion and suggest a six-hour drying period as a safe interval for field applications.

The findings of the present study for the impact of rainfall on insecticide efficacy in controlling *G. molesta* in apple trees allow for a practical conclusion. There is little justification for immediate reapplication of the tested insecticides after rainfall with a duration of less than one hour. Despite the importance of this result in reducing production costs and environmental contamination risks, the data obtained cannot be extrapolated to other insecticides due to the intrinsic properties of each product. Wise et al. (2017) demonstrated that rainfall can have diverse effects on the performance of insecticides applied to apple trees, ranging from a reduction in control efficacy due to significant insecticide loss to the maintenance of control efficacy despite product loss or even exhibiting resistance to wash-off by rainfall.

Thus, further experiments and tests are needed to provide more precise technical recommendations for insecticide reapplication strategies after rainfall events for controlling *G. molesta*. These studies should consider the specific physicochemical properties of each insecticide, as well as other factors such as rainfall intensity,

longer rainfall durations than those tested in the present study, the use of adjuvants, and the efficacy of different insecticides approved for the control of *G. molesta* in apple trees. Additionally, evaluating the residual activity of other molecules used to control apple pests under rainfall conditions would be valuable for expanding the scope of recommendations.

4. Conclusions

1. Rainfall at intensity of 50- or 10-mm h^{-1} does not significantly affect the final control efficacy against *G. molesta* 60 minutes after the onset of rainfall.

2. The control efficacy of insecticides against *G. molesta* in apple trees increases during the initial 30 minutes of rainfall due to redistribution of insecticides on the plant.

3. The redistribution of pesticides on the plant is rapid under a rainfall intensity of 50 mm h^{-1} and slower and more prolonged under a rainfall intensity of 10 mm h^{-1}.

4. A drying time of six hours on apple tress is sufficient to maintain control efficacy for phosmet and chlorantraniliprole insecticides against *G. molesta*, regardless of rainfall intensity.

Transparency of Data

Available data: The entire data set that supports the results of this study was published in the article itself.

Author Contribution Statement

	RSSS	DFK	JOA	LG	SAMA	MCB
Conceptualization	🟩	🟩	🟩	🟩	🟩	🟩
Data curation	🟩	🟩	🟩	🟩	🟩	🟩
Formal analysis	🟩	🟩	🟩	🟩	🟩	🟩
Funding acquisition				🟩	🟩	
Investigation	🟩	🟩	🟩	🟩	🟩	🟩
Methodology	🟩	🟩	🟩	🟩	🟩	🟩
Project administration	🟩			🟩	🟩	
Resources				🟩	🟩	🟩
Supervision	🟩	🟩		🟩	🟩	🟩
Validation	🟩	🟩	🟩	🟩	🟩	🟩
Visualization	🟩	🟩	🟩	🟩	🟩	🟩
Writing – original draft	🟩	🟩	🟩	🟩	🟩	🟩
Writing – review and editing	🟩	🟩		🟩	🟩	🟩

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