# Residues and dissipation of imidacloprid in avocado fruit

Residualidad y disipación de imidacloprid en frutos de palto

Residualidade e dissipação do imidaclopride no abacateiro

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## Abstract

Imidacloprid is a neonicotinoid insecticide used to control insect pests in avocado (*Persea americana*); its excessive application could generate residues above the maximum residue limits (MRL) in the fruit, causing a serious health risk to consumers. The objective of this work was to determine the residues and dissipation of imidacloprid in avocado fruit, Hass variety. The treatments were the doses of imidacloprid (0.5, 1.0 and 1.5 mL.L$^{-1}$) under the commercial formulation Thunder 350SC and the forms of application (sprayed to foliage and drip at the foot of the plant). There were six treatments in a completely randomized experimental design with three replications and 18 experimental units (plants). Quanti ication was by HPLC (QuEChERS). The evaluations were carried out on two matrices (avocado fruit peel and pulp) at 1, 3, 7 and 14 days after the application of Imidacloprid. The application of the 0.5 mL.L$^{-1}$ dose by drip at the foot of the plant resulted in lower residual and a higher percentage of dissipation in both matrices, higher daily dissipation rate in the pulp, with imidacloprid concentrations that did not exceed the MRL (0.7 mg.kg$^{-1}$). The application of 1.5 mL.L$^{-1}$ by spraying resulted in higher residual, and in a lower percentage of dissipation in both matrices, with imidacloprid concentrations in the peel exceeding the MRL at 7 and 14 days. In the pulp, none of the treatments exceeded the MRL.

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## Resumen

Imidacloprid es un insecticida neonicotinoide que se utiliza para controlar insectos plaga en el cultivo de palto (*Persea americana*), su aplicación excesiva pudiera generar residuos por encima de los límites máximos de residuos (LMR) en los frutos ocasionando un grave riesgo para la salud de los consumidores. El objetivo de este trabajo, fue determinar la residualidad y disipación de imidacloprid en frutos de palto, variedad Hass. Los tratamientos fueron las dosis de Imidacloprid (0,5; 1,0 y 1,5 mL.L$^{-1}$) bajo la formulación comercial Thunder 350SC y las formas de aplicación (Asperjado al follaje y goteo a pie de planta). Se conformaron seis tratamientos en un diseño experimental completamente al azar con tres repeticiones, 18 unidades experimentales (plantas). La cuantificación fue mediante HPLC (QuEChERS). Las evaluaciones se realizaron en dos matrices (cáscara y pulpa de frutos de palto) a 1, 3, 7 y 14 días de la aplicación de imidacloprid. La aplicación de la dosis de 0,5 mL.L$^{-1}$ por goteo a pie de planta originó menor residualidad y mayor porcentaje de disipación en ambas matrices, mayor tasa de disipación diaria en la pulpa, con concentraciones de imidacloprid que no superaron el LMR (0,7 mg.kg$^{-1}$). La aplicación de 1,5 mL.L$^{-1}$ por aspersión ocasionó mayor residualidad, menor porcentaje de disipación en ambas matrices, con concentraciones de imidacloprid en la cáscara que superaron los LMR a 7 y 14 días. En la pulpa ninguno de los tratamientos superó el LMR.


**Palabras clave:** *Persea americana*, neonicotinoide, periodo de carencia, plaguicida.


## Resumo

Imidaclopride é um inseticida neonicotinóide usado para controlar pragas de insetos no abacate (*Persea americana*), sua aplicação excessiva poderia gerar resíduos acima dos limites máximos de resíduos (LMR) na fruta, causando um sério risco à saúde dos consumidores. O objetivo deste estudo foi determinar o resíduo e a dissipação do imidaclopride na fruta abacate, variedade Hass. Os tratamentos foram doses de imidaclopride (0,5, 1,0 e 1,5 mL.L$^{-1}$) sob a formulação comercial Thunder 350SC e a formas de aplicação (pulverizado sobre a folhagem e gotejado no pé da planta). Houve seis tratamentos em um projeto experimental completamente aleatório com três réplicas, 18 unidades experimentais (plantas). A quantificação foi feita por HPLC (QuEChERS). As avaliações foram realizadas em duas matrizes (casca de fruta abacate e polpa) em 1, 3, 7 e 14 dias após a aplicação do imidacloprid. A aplicação da dose de 0,5 mL.L$^{-1}$ por gotejamento no pé da planta resultou em menor resíduo e maior porcentagem de dissipação em ambas as matrizes, maior taxa de dissipação diária na polpa, com concentrações de imidaclopride que não excederam o LMR (0,7 mg.kg$^{-1}$). A aplicação de pulverização de 1,5 mL.L$^{-1}$ resultou em maior resíduo, menor porcentagem de dissipação em ambas as matrizes, com concentrações de imidaclopride na casca excedendo os LMRs aos 7 e 14 dias. Na polpa, nenhum dos tratamentos excedeu o LMR.


**Palavras-chave:** *Persea americana*, neonicotinoide, período de retirada, pesticida.

## Introduction

The application of pesticides is a common practice in conventional agro-productive systems of food production (Bondareva and Fedorova, 2021). However, there is sufficient information that demonstrates the risks involved in their indiscriminate use, which could cause negative effects on human health and deterioration of agricultural ecosystems (Chandra *et al*., 2021; Zikankuba *et al*., 2019; Durán-Quirós *et al*., 2017; Ettiene *et al*., 2017).

Additionally, overdosing or non-compliance with the waiting periods of insecticides can generate residues not allowed in food (Durán-Quirós *et al*., 2017) that when exceeding the MRL become contaminating substances that could originate adverse effects on human health (Pereira *et al*., 2021, Yilmaz, 2017).

Therefore, a criterion of great importance in the use of an insecticide is the knowledge of the residues and their dissipation period in the harvested food (Chandra *et al*., 2021). On the other hand, the toxic effect and the dissipation period of insecticide residues depend on the characteristics of the applied product, and are conditioned by physical, mechanical, chemical, biological, and climatological factors of the environment (Zikankuba *et al*., 2019).

Imidacloprid is the most widely used neonicotinoid insecticide in the phytosanitary management of various crops (Pang *et al*., 2020). Nowadays, its use is extensive for the control of various pests in agricultural production, causing significant amounts of residues in harvested food and the environment (Peng *et al*., 2021; Zhou *et al*., 2021) with impacts and risks to the health of consumers and contamination of ecosystems (Hladik *et al*., 2018; Fernández and Giménez, 2005). These insecticides are degraded by multiple hydroxylation reactions and aromatic ring cleavage, forming non-absorbent intermediates such as carbon dioxide and other minerals (Joice *et al*., 2019).

Avocado is a product with great acceptance in international markets (Zambrano, 2014). Its management in the field requires great care regarding the insecticides used for pest control, because they could be contaminated with persistent residues (García-Vargas *et al*., 2020).

In Peru, imidacloprid is the most frequently neonicotinoid used for plant protection of avocado crops (Collavino and Giménez, 2008; Jawad and Hermize, 2020; Mohapatra *et al*., 2019; Peng *et al*., 2021). According to Castillo *et al*. (2020), many growers make insecticide applications indiscriminately to protect their crops without considering the toxicity of the product due to chemical residues, so there is concern from avocado fruit producers regarding the presence of insecticide residues, to comply with international marketing standards, especially for exports, due to the fact that these markets are very demanding in terms of food safety (Delgado-Zegarra *et al*., 2018).

Previous reports (Agriquem, 2021), reported residues of imidacloprid, spirotetramat, prochloraz, 2-4-6 trichlorophenol, and methomyl in avocado lots exported from Peru to countries of the European Union. Therefore, the quantitative assessment of imidacloprid residues according to the form of application is an essential issue for avocado growers, in order to comply with national and international requirements regarding the MRL for marketing.

In this context, the objective of the research was to determine the residues and dissipation of imidacloprid in avocado fruit (*Persea americana*) of the Hass variety by the effect of the application of the insecticide in three doses and two forms of application: sprayed to foliage and drip at the foot of the plant.

## Materials and methods

**Trial location**

The research was carried out in an avocado plantation of the Hass variety of the Majes Irrigation of Arequipa, Peru; located at latitude 16°21′11″ (S), longitude 72°11′27″ (W) and 1410 masml altitude, where an arid zone climate with humidity deficiency prevails in all seasons of the year. During the research period, the average daily temperature was between 19 and 24°C, and relative humidity was between 48 and 52%; no precipitation was recorded.

**Edaphic characteristics and avocado plantation management**

The soil texture was loamy sand; sand: 84.8 %; silt: 8.8 %; clay: 6.4 %; organic matter: 1.32 %; total N: 0.07 %; available P: 21.25 $mg.kg^{-1}$; total K: 285.5 $mg.kg^{-1}$; pH: 7.2; EC: 0.85 $mS.cm^{-1}$; C.I.C.: 8.56 $cmol.kg^{-1}$; these characteristics were suitable for avocado planting.

The avocado plantation was in the second year of production with a density of 500 $plants.ha^{-1}$, and with a spacing of 5 x 4 m. To enhance production, nutrients were applied via fertigation at doses of 300, 45, 250, 10, and 50 $kg.ha^{-1}$ of N, P, K, Mg, and Ca, respectively. The Thunder 350 SC commercial formulation was used, whose active ingredient is imidacloprid (350 $g.L^{-1}$) of the neonicotinoid family. It is a systemic insecticide that acts by contact and ingestion for the control of "spider mites" (*Panonychus citri, Oligonychus* spp.), and stinging-sucking insects such as thrips and bugs, pests of great importance in the avocado crop at the doses, and in the forms indicated in the treatments. The commercial formulation Thunder 350 SC refers to an MRL (Maximum Residue Limit) of 0.7 ppm ($mg.kg^{-1}$), and a withdrawal period of seven (7) days. FAO and WHO have not yet approved MRL for imidacloprid on avocados. Copper sulfate was also applied for rot prevention via the irrigation system at a dose of 4 $L.ha^{-1}$. Fruits were harvested using scissors and leaving 3 to 5 mm of peduncle on each fruit.

**Experimental design and statistical analysis**

Six treatments (three doses in two forms of application) were randomly applied in the avocado plantation in a completely randomized experimental design with three replications, and 18 experimental units (avocado plants). For the treatments studied, imidacloprid insecticide was applied at three doses: 0.5, 1.0, and 1.5 $mL.L^{-1}$, under the commercial formulation Thunder 350SC in two forms of application: sprayed to the foliage (AAF), and drip at the foot of the plant (GPP). The spray application was carried out using a knapsack sprayer and the drip application was via an adapted irrigation system. For this, the insecticides were diluted in water and applied homogeneously in the spray matrix of each tree in an equivalent volume of 800 $L.ha^{-1}$. In the drip system, 350 $L.ha^{-1}$ were used. Imidacloprid was applied only once during the period of growth and fruit maturity (105 days after fruiting).

The records of the evaluations were subjected to analysis of variance. Tukey's multiple range test ($p < 0.05$) was used to establish significant differences between treatments. A simple linear regression analysis with logarithmic arrangement was performed to elaborate the imidacloprid dissipation curves. Statistical analyses were performed with RStudio.

**Sampling of avocado fruits**

Avocado fruits were collected during the period of growth and maturity, the samples were taken randomly on the first, third, seventh, and fourteenth day of the application of the treatments; three avocado fruits were sampled for each experimental unit, these were taken from the central part of the plant in the middle of the vegetative period. The samples were placed in a cooler with ice at an average temperature of 4°C, and transferred to the Agro-environmental Analysis Laboratory of the National University of Saint Augustine, Peru for the corresponding analytical determinations.

**Analytical determination of imidacloprid**

**Reagents, materials, and equipment**

The HPLC-grade imidacloprid standard was purchased from Sigma Aldrich with a purity percentage of 99.5 %. The solvents used were acetonitrile and methanol (HPLC grade). Ultrapure water with a resistivity of 18.2 $M\Omega.cm^{-1}$ obtained from the Simplicity UV Merck Millipore purification system was used. QuEChERS AOAC 2007.01 dispersion and extraction kits, were used; a Purospher Star C18 column (RP-18e 150 x 4.6 mm, 5 µm), a Hitachi High-Tech Chromaster for high-performance liquid chromatography with diode array (HPLC - DAD), and a nitrogen concentrator (Labtech Multivap 6).

**Extraction and cleaning of the sample**

For the extraction, 10.0 g of homogenized sample was used with 10 mL of acetonitrile (ACN) adding the QuEChERS AOAC 2007.01 extraction kit (6 g of MgSO4, 1.5 g of sodium citrate), it was manually shaken for one minute and centrifuged for three (3) minutes at 3,300 rpm with a universal centrifuge 320, Hettich. Dispersive solid phase extraction (d-SPE) was used to clean up the extracts; for that, the supernatant of the product of the previous extraction was used, adding the QuEChERS AOAC 2007.01 dispersion kit (50 mg secondary primary amine, 150 mg MgSO4), the mixture was manually shaken for one minute and centrifuged for three (3) minutes at 3,300 rpm. Then, 3.5 mL of the upper layer was taken, subsequently, the sample was concentrated to dryness using $N_2$ (g), then the residue, was reconstituted with the mobile phase to one (1) mL, finally, the resulting solution was filtered with a 45 µm Nylon filter for subsequent analysis by HPLC - DAD (AOAC, 2007).

**Separation of imidacloprid by high-performance liquid chromatography (HPLC)**

For the separation of imidacloprid by HPLC, a mobile phase composed of acetonitrile (100%) was employed, using a diode array detector (DAD) at a wavelength of 270 nm, identifying the imidacloprid signal with a retention time of 4.7 min. The method was validated to determine the parameters of linearity, sensitivity, precision, and accuracy (Aguirre *et al*., 2001).

A calibration curve was prepared from the pure imidacloprid standard, using six concentrations (0.2; 0.5; 0.8; 1.1; 1.4, and 1.7 $mg.L^{-1}$) obtaining a coefficient of determination ($r^2$) of 0.9995; with limits of detection (LOD) and quantification (LOQ) of 0.0116, and 0.0156 $mg.L^{-1}$, respectively. The relative standard deviation (RSD) was 0.46%. The accuracy calculated by the percent recovery method (%R) was 97.54 %. The results prove that the method is linear ($r^2 >$ 0.995), precise (RSD < 2.7%), and accurate with a %R between 90 and 110 % (Aguirre *et al*., 2001).

**Residues of imidacloprid**

The concentration of imidacloprid in the peel (exocarp), and pulp (mesocarp) of avocado fruit was determined. Records were taken 1, 3, 7, and 14 days after the application of treatments. The results were expressed in $mg.kg^{-1}$.

**Daily dissipation rate of imidacloprid**

The daily dissipation rate was obtained by linear regression, transforming the data by means of the following logarithmic equation:

$$Y = B0e^{B1Xi}$$

Where:

Y: dependent variable (calculated daily dissipation rate); B0: corrected dissipation values; B1: dissipation rate; X : elapsed time after imidacloprid application.

For each treatment, a dissipation curve was constructed with the corresponding equation, using the corrected dissipation values.

## Results and discussion

**Residues of Imidacloprid in peel and pulp of avocado fruit**

Statistical differences were observed among treatments in the four evaluation periods (table 1) with coefficients of variability between 2.45 % and 7.79 %. In all evaluations on peel and pulp, a tendency to decrease the initial imidacloprid concentration (1st day) was evidenced as the evaluation time increased (3, 7, and 14 days).

In the peel, the highest initial concentration of imidacloprid was 0.923 $mg.kg^{-1}$ by the application of the 1.5 $mL.L^{-1}$ AAF dose. After 14 days it decreased to 0.726 $mg.kg^{-1}$ , representing 21.3 % dissipation. The lowest residual was observed with the application of the 0.5 $mL.L^{-1}$ GPP dose with an initial concentration of 0.285 $mg.kg^{-1}$, and after 14 days it decreased to 0.175 $mg.kg^{-1}$, representing 38.6 % dissipation.

Imidacloprid was not detected in the pulp on the first day of evaluation. On the third day, the highest concentration (0.563 $mg.kg^{-1}$) was recorded by the application of 1.5 $mL.L^{-1}$ AAF, and on the fourteenth day, it decreased to 0.384 $mg.kg^{-1}$ with 35.3 % dissipation. The lowest residual in the pulp was observed after three days when applying the 0.5 $mL.L^{-1}$ GPP dose (0.086 $mg.kg^{-1}$), and after 14 days it decreased to 0.022 $mg.kg^{-1}$ achieving 74.4 % dissipation.

According to Zhai *et al*. (2022) and Durán-Quirós *et al*. (2017), pesticide residues gradually decrease over time, and the rate of decrease varies by various environmental factors, and plant and pesticide characteristics.

The trend in the results showed that the residues of imidacloprid were lower when the doses were applied by drip application at the foot of the plant, both in the peel and in the pulp. The peel had a higher concentration of imidacloprid than the pulp.

With respect to the percentage of imidacloprid dissipation, this was higher in the pulp than in the peel. The application of imidacloprid doses by drip resulted in a higher percentage of dissipation compared to the application by spraying to the foliage.

Regarding the best performance of the 0.5 $mL.L^{-1}$ GPP dose, Collavino and Giménez (2008) explained that the imidacloprid insecticide is characterized by a systemic mode of action, therefore its slow dosage form would facilitate its dissipation; on the other hand, spray applications at high doses may result in a greater residual and lower percentage of dissipation. Although, Zhou *et al*. (2021) report that the differences in the initial and final concentration of imidacloprid for each treatment can be attributed to the diameter and mass of the avocado fruit, the smaller fruits having a larger specific surface area have a greater accumulation of the pesticide; and as the diameter of the fruit increases, the concentration of the pesticide decreases. On the other hand, Fernandez and Gimenez. (2005) indicate that foliar application of pesticides generally causes a good portion of the product to be deposited on the soil, but the adherence to the avocado fruit peel associated with the high temperature and low atmospheric relative humidity would have caused a higher initial concentration of imidacloprid.

A greater residual of imidacloprid was obtained in the peel in relation to the pulp; in this regard, Pang *et al*. (2020) pointed out that in fruits for daily consumption, the peel acts as a natural protector against external agents; therefore, it is obvious to assume that the residues of imidacloprid would be retained in the peel and only a minimal amount would penetrate the pulp. In this sense, Joice *et al*. (2019) and Pereira *et al*. (2021), point out that in the initial concentration or initial deposit, the lower layer of the pesticide is strongly adhered to the plant surface. Likewise, Pang *et al*. (2020) and Zikankuba *et al*. (2019), emphasize that the physical characteristics, chemical composition, and presence of waxes of the plant or fruits affect the retention of a pesticide, and in the case of avocado fruit, on the surface of its peel there is a dense, thick and uniform layer of wax that covers the epidermal surface without interruption (Barrientos *et al*., 1996), so this layer would have allowed a uniform adherence of imidacloprid when the doses were applied by spraying to the foliage causing greater residual on the peel, compared to a drip application at the foot of the plant. In

**Table 1. Imidacloprid residues ($mg.kg^{-1}$) in peel and pulp of avocado fruit in four evaluation periods after application.**

| Treatments | 1 day | | 2 days | | 7 days | | 14 days | |
|---|---|---|---|---|---|---|---|---|
| | Peel | Pulp | Peel | Pulp | Peel | Pulp | Peel | Pulp |
| 0.5 $mL.L^{-1}$ AAF | 0.784±0.071c | 0 | 0.705±0.010d | 0.153±0.004b | 0.612±0.015c | 0.128±0.006c | 0.428±0.018c | 0.105±0.007c |
| 0.5 $mL.L^{-1}$ GPP | 0.285±0.007a | 0 | 0.203±0.009a | 0.086±0.006a | 0.198±0.008a | 0.053±0.003a | 0.175±0.008a | 0.022±0.004a |
| 1.0 $mL.L^{-1}$ AAF | 0.856±0.073cd | 0 | 0.790±0.004e | 0.30±0.0074d | 0.768±0.014d | 0.288±0.004d | 0.684±0.041d | 0.203±0.011d |
| 1.0 $mL.L^{-1}$ GPP | 0.362±0.051a | 0 | 0.242±0.005b | 0.109±0.007a | 0.206±0.01a | 0.083±0.005b | 0.193±0.004a | 0.065±0.003b |
| 1.5 $mL.L^{-1}$ AAF | 0.923±0.028d | 0 | 0.865±0.027f | 0.563±0.012e | 0.783±0.020d | 0.475±0.006e | 0.726±0.009d | 0.384±0.005e |
| 1.5 $mL.L^{-1}$ GPP | 0.517±0.017b | 0 | 0.422±0.010c | 0.198±0.012c | 0.376±0.004b | 0.124±0.007c | 0.291±0.006b | 0.091±0.004c |
| CV (%) | 7.79 | - | 2.45 | 3.66 | 2.66 | 2.79 | 4.57 | 4.31 |

Equal letters in each column indicate that there are no significant statistical differences between treatments according to Tukey ($p \leq 0.05$). CV: coefficient of variability. AAF: sprayed to the foliage. GPP: drip at the foot of the plant. ±: standard deviation.

avocado pulp, applications of all treatments did not exceed the MRL for imidacloprid in all evaluation periods.

On avocado peel (figure 1), on the first day of evaluation, all doses applied by spraying to the foliage exceeded the MRL (0.7 mg.kg$^{-1}$) for imidacloprid indicated by the manufacturer. None of the doses applied exceeded the MRL (1.0 mg.kg$^{-1}$) proposed by the Code of Federal Regulations (CFR, 2022). FAO and WHO, have not yet established MRL for imidacloprid on avocado.

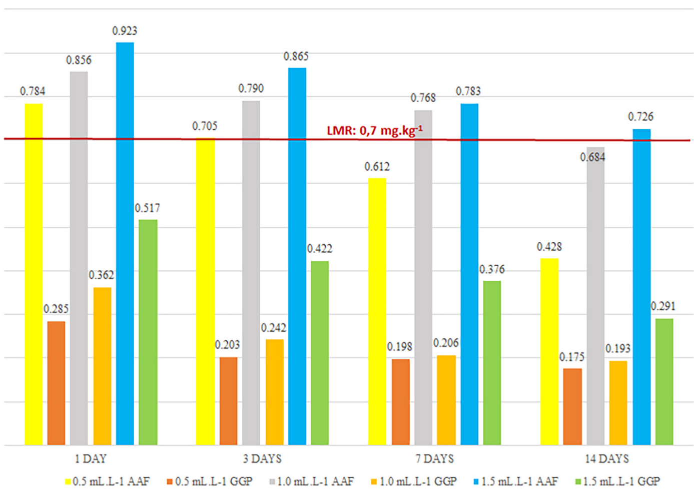


**Figure 1. Residues of imidacloprid (mg.kg$^{-1}$) in avocado peel for each treatment compared to the MRL.**

At seven days, considered to be the withdrawal period for the commercial formulation, the imidacloprid doses of 1 and 1.5 mL.L$^{-1}$ AAF exceeded the MRL. At 14 days, only the 1.5 mL.L$^{-1}$ AAF dose exceeded the MRL. In the peel, none of the imidacloprid treatments applied by drip exceeded the MRL in all evaluation periods. In this regard, Durán-Quirós *et al*. (2017) indicate that the withdrawal period is the period of time allowed for a pesticide to degrade below the MRL and is influenced by climatic conditions and the pernicious effect cycle of the pesticide. The Peruvian Technical Sanitary Standard (NTP:128/MINSA/2016/DIGESA), indicates that the MRL for imidacloprid in avocado of the Hass variety is 1 mg.kg$^{-1}$, according to PROMPERU (2022), similar MRL is allowed for avocado exports to Europe, USA, Canada, Chile, China, and Costa Rica; therefore, applications of all treatments would not affect the sanitary quality of avocado for these markets.

For the Japanese market, the MRL is 0.7 mg.kg$^{-1}$ (PROMPERU, 2022), in this case, the application of 1.5 mL.L$^{-1}$ AAF would limit its commercialization due to the residues of imidacloprid detected at the peel level 14 days after its application. At seven days, which is the withdrawal period, the MRL in peel was also exceeded by applications of 1.0 and 1.5 mL.L$^{-1}$ AAF, limiting its commercialization. In the pulp, the MRL was not exceeded.

**Daily dissipation rate of imidacloprid in the peel and pulp of avocado fruit**

In the peel, the highest daily dissipation rate was due to the effect of the 0.5 mL.L$^{-1}$ AAF dose (table 2), for each day that the concentration of imidacloprid elapsed, it decreased by 0.01993 mg.kg$^{-1}$. The lowest dissipation rate was for the application of 1.0 mL.L$^{-1}$ AAF.

**Table 2. Daily dissipation rate of imidacloprid (mg.kg$^{-1}$) and corrected dissipation values in the peel and pulp of avocado fruit for each treatment.**

| Treatments | Peel | | Pulp | |
|---|---|---|---|---|
| | TDD | VDC | TDD | VDC |
| 0.5 mL.L$^{-1}$ AAF | -0.01993 | 0.91744651 | -0.014621 | 0.45884721 |
| 0.5 mL.L$^{-1}$ GPP | -0.01319 | 0.55254522 | -0.054234 | 0.40621204 |
| 1.0 mL.L$^{-1}$ AAF | -0.006944 | 0.93365153 | -0.016632 | 0.63727946 |
| 1.0 mL.L$^{-1}$ GPP | -0.016733 | 0.60032386 | -0.019792 | 0.39892614 |
| 1.5 mL.L$^{-1}$ AAF | -0.007639 | 0.96262052 | -0.014887 | 0.81023577 |
| 1.5 mL.L$^{-1}$ GGP | -0.018031 | 0.7466625 | -0.029368 | 0.52251844 |

TDD: Daily dissipation rate. VDC: Corrected dissipation values. AAF: sprayed to the foliage. GPP: drip at the foot of the plant.

In the pulp, the highest rate of dissipation of imidacloprid was by the application of the 0.5 mL.L$^{-1}$ GPP dose, for each day elapsed, the concentration of imidacloprid decreased by 0.054234 mg.kg$^{-1}$. It was found that in the pulp the dissipation rate was higher with respect to the dissipation in peel.

The dissipation curve model corresponds to a first order logarithmic equation in both matrices evaluated. Figure 2 shows a trend generated by the application of the treatments where the concentration of imidacloprid in the avocado peel dissipates gradually as the application time elapses, being more accentuated from three days after the application of the treatments (DDAT).

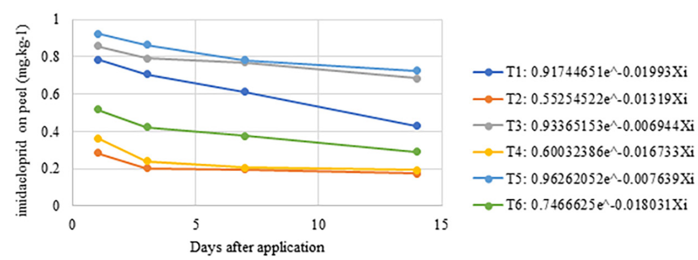


**Figure 2. Dissipation curve of imidacloprid in avocado peel. AAF: sprayed to the foliage.** GPP: drip at the foot of the plant. T1: 0.5 mL.L$^{-1}$ AAF. T2: 0.5 mL.L$^{-1}$ GPP. T3: 1.0 mL.L$^{-1}$ AAF. T4: 1.0 mL.$^{L-1}$ GPP. T5: 1.5 mL.L$^{-1}$ AAF. T6: 1.5 mL.L-$^{1}$ GPP.

The figure 3 shows the same trend in the pulp but with greater evidence from the seven DDAT.

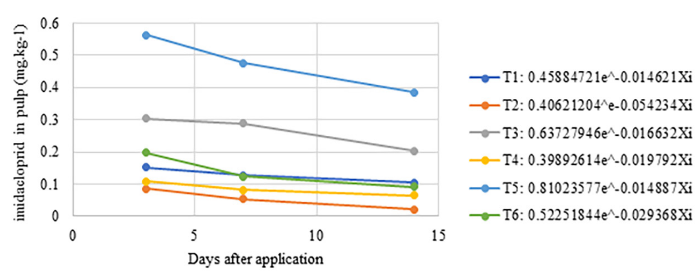


**Figure 3. Dissipation curve of imidacloprid in avocado pulp. AAF: sprayed to the foliage.** GPP: drip at the foot of the plant. T1: 0.5 mL.L$^{-1}$ AAF. T2: 0.5 mL.L$^{-1}$ GPP. T3: 1.0 mL.L$^{-1}$ AAF. T4: 1.0 mL.L$^{-1}$ GPP. T5: 1.5 mL.L$^{-1}$ AAF. T6: 1.5 mL.L$^{-1}$ GPP.

The figure 4 shows the logarithmic dissipation of imidacloprid for the two types of application, evidencing that AAF and GPP also caused a staggered dissipation in the peel and pulp of the avocado as time increases.

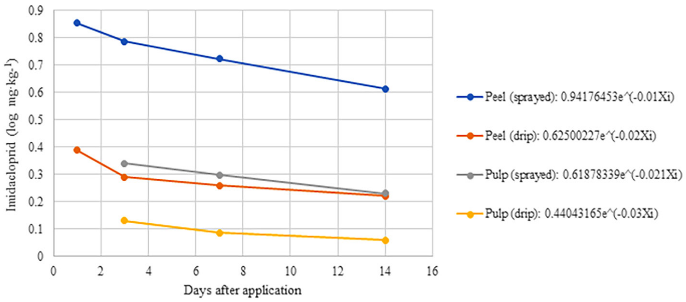


**Figure 4. Logarithmic dissipation of imidacloprid for the two types of application (spray and drip) on avocado peel and pulp.**

In a study of imidacloprid dissipation by Zhai *et al*. (2022) in Chinese onion (*Allium tuberosum*) they observed dissipation dynamics consistent with first order kinetics, with final residual levels between 0.00923 and 0.166 $mg.kg^{-1}$ below the MRL (1 $mg.kg^{-1}$) with a risk assessment index <1 indicating that they are safe for consumption.

Similar results were obtained by Mohapatra *et al*. (2019) in the evaluation of imidacloprid residue levels in pomegranate fruits (*Punica granatum*) for two years, they found first order reaction kinetics with a degradation half-life of 8 to 11.1 days; the MRL of imidacloprid in pomegranate were lower than their MRL (1 $mg.kg^{-1}$), with a pre-harvest interval of only one day. On the other hand, Jawad & Hermize (2020) in an analysis of imidacloprid residues on fruits of sweet Karisma bell pepper (*Capsicum annum* L), reported that after eight days, the residual of imidacloprid was 0.07 $mg.kg^{-1}$ lower than the MRL.

According to Zhai *et al*. (2022) and Hladik *et al*. (2018), the agroecological zone where a pesticide is applied would have its effect mainly on the daily dissipation rate of the residue. In this regard, Pereira *et al*. (2021), and Zhou *et al*. (2021), highlight that in arid areas, high temperatures, and wind action would be the determining factors in pesticide dissipation. In the same order of ideas, Zhou *et al*. (2021), and Peng *et al*. (2021) state that the dissipation dynamics establishes a rapid initial decrease depending on climatic conditions. According to Pang *et al*. (2020), the dissipation of systemic insecticides such as imidacloprid in avocado fruit pulp is greater than the dissipation of insecticides in the peel; this degradation is complex and the rate of internal metabolization is variable and is determined by enzymatic actions, characteristic of plant tissue. However, Gonzalez (2009) refers that the residues and dissipation of a pesticide are influenced by the application coverage and the size of the application drop; the smaller the pesticide drop, the greater the persistence of the pesticide and therefore the greater the residual. On the other hand, Mohapatra *et al*. (2019), state that the increase in temperature facilitates several processes involved in the dissipation of an insecticide, so an increase in temperature favors the solubility of the insecticide. Imidacloprid presents high solubility in water, favoring its dissipation.

The information provided by this research is of utmost importance for phytosanitary safety and food safety, demonstrating that the manufacturer's recommendation regarding the insecticide withdrawal period (7 days) is not met when 1.0 and 1.5 $mL.L^{-1}$ AAF are applied, because the residual of imidacloprid in the peel exceeded the MRL. No levels exceeding the MRL were detected in the pulp. In this sense, it is advisable for future research to develop a more appropriate and representative withdrawal period for avocado cultivation in arid areas where its cultivation is of great importance.

## Conclusions

It was determined that the application of imidacloprid by drip at the foot of the plant at a dose of 0.5 $mL.L^{-1}$ caused the lowest residual, and the highest percentage of dissipation in the peel and pulp of avocado fruits, reaching the highest daily dissipation rate in the pulp. Spraying imidacloprid to the foliage at a dose of 1.5 $mL.L^{-1}$ caused the highest residual, and the lowest percentage of dissipation in the peel and pulp of the fruits, generating residues of imidacloprid in the peel that exceeded the MRL. None of the treatments exceeded the MRL in the pulp. The dissipation rate was higher in the pulp than in the peel. The imidacloprid dissipation curve model was fit to a first-order logarithmic equation.

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