Technical Report

Dissipation of the pesticides fipronil, cypermethrin, and tebuconazole in vegetables: A case study in Thua Thien-Hue province, Central Vietnam

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This study was designed to understand the dissipation of fipronil, cypermethrin, and tebuconazole in green onions and mustard greens grown in Central Vietnam. A field trial on ca. 400 m² was implemented for two months with three different cropping regimes (natural plot—fully exposed to natural conditions; bed plot—fenced in by plastic sheets with an open roof; and protected plot—fully covered by plastic sheets) for each vegetable. A first-order kinetic model was successfully employed to interpret the dissipation data of each studied pesticide. A comparing the dissipation rate constants obtained under the same crop and growing regime between chemicals suggested that, among the chemicals examined, fipronil dissipated most readily. The pesticides were also proven to be more persistent in crops grown in protected plots than those grown in natural plots. The half-lives for fipronil, cypermethrin, and tebuconazole fluctuated, occurring at 0.4–2.2 days, 2.0–6.0 days, and 0.9–3.3 days, respectively.

Keywords: cypermethrin, dissipation, fipronil, tebuconazole, vegetables.

Electronic supplementary materials: The online version of this article contains supplementary materials (Supplemental Tables S1–S8), which is available at https://www.jstage.jst.go.jp/browse/jpestics/

Introduction

Vietnam is a predominately agricultural country located in a typical tropical climate region of Asia. In 2017, Vietnam was named the world’s seventh largest vegetable producer1) with a diversity of cultivars. A survey campaign conducted in March 2018 (data not shown) found the two most commonly grown and consumed vegetables in Thua Thien-Hue Province of Central Vietnam to be green onions (Allium fistulosum) and mustard greens (Brassica juncea), which are both leafy vegetables of short-term crops. Mustard greens have small and slightly rounded leaf stalks and are usually harvested at around 40–45 days after transplantation. Green onions have concentric leaves, with a growing cycle of about 45–55 days before harvest. Within the study region, vegetable crops are commonly cultivated on plots that are either completely exposed to natural conditions, with fences surrounding the crops to separate plots, or on fenced plots fully covered by a roof to prevent damage to the crop from heavy rain or animal invasions. However, as productivity has been strongly affected by pests such as thrips, or diseases including botrytis leaf blight, a wide variety of pesticides, especially fungicides and insecticides, have been frequently applied.2,3) A survey undertaken in 2018 in Thua Thien-Hue revealed that three of the most frequently applied insecticides in green onion and mustard green cultivation were cypermethrin, fipronil, and tebuconazole. These three pesticides have been registered for leafy vegetable cultivation (including green onions and mustard greens) in Vietnam under different trade names, according to Circular No.10/2019/TT-BNNPTNT.4) Cypermethrin, a mixture of eight stereoisomers, belongs to the group of synthetic pyrethroid insecticides.5) Fipronil is a member of a relatively new class of pesticides, the phenyl-pyrazole insecticides.6) Tebuconazole is a triazole fungicide that is also chiral and systemic. It is widely used thanks to its effectiveness against powdery mildew and gray mold.7)

In recent decades, pesticide-fate studies have been a topic of significant interest worldwide. The pesticide-degradation process in plants can be of physicochemical (volatilization, hydrolysis, photolysis, oxidation, reduction, etc.) and/or biochemical in nature.8) Further, pesticide dissipation is influenced by the totality of several factors, including plant growth (dilution), climate (rainfall, sunlight, temperature, etc.), application method, uptake (of leaf, stem, and root), pesticide properties, and possibly
even plant species. It has been noted that pesticides are likely
to dissipate faster in the soil found in tropical climates than in
that found in temperate regions. However, this conclusion has
not been verified in plants. Reports have been published on the
dissipation of pesticides, including fipronil, cypermethrin, tebu-
conazole, and others, in vegetables under different climate con-
ditions with different cultivation techniques elsewhere. For in-
stance, research has been performed in Canada, Spain, and
India, often with different cultivars such as Chinese cabbage,
mangoes, cowpeas, tomatoes, and pomegranates. These
studies imply that the pesticide dissipation could be manipu-
lated by using different cropping regimes.

The exponential decay equation helps to significantly predict
the half-life of individual pesticides as well as the theoretical
residue of the target pesticide in a plant at a specific time. In
addition, studies elsewhere have developed different dissipation
models of pesticides in soil or plants using either bi-exponential
or mono-exponential models. The review conducted by Fantke
and Juraske provided an overview of nine kinetic models to
predict pesticide-dissipation half-lives in plants. In most of the
cases used for pesticide-fate analysis in plants, first-order kinet-
ics fits the measured data set well. However, rarely have stud-
ies compared the impact of cropping practices under different
regimes on the dissipation behaviors of pesticides in vegetables.

In this study a field experiment was designed to manipulate
the dissipation of three commonly used pesticides: fipronil, cy-
permethrin and tebuconazole, in green onions and mustard
greens under three different cropping processes. In addition, re-
searchers evaluated whether the first-order kinetic model can
be applied to fit the degradation data of the studied pesticides.
Finally, researchers applied the model to estimate the half-life
values for the three pesticides in the two vegetables being stud-
ied. To reduce experimental complications, this study assumed
that the amount of pesticide uptake from the soil by plants is off-
set by the dilution amount of plant growth. Therefore, only the
measured residue of the pesticide in the plants was considered.

Materials and Methods

1. Chemicals and reagents
Fipronil, cypermethrin, and tebuconazole standards, surrogate
standard delta-hexachlorocyclohexane (δ-HCH), and labeled
internal standard phenanthrene-D10 were obtained from Sigma-
Aldrich (purity >97%, USA) for use in this study. All em-
ployed solvents (n-hexane, acetone, and toluene) were of HPLC
grade (J.T. Baker, Netherlands). Glass fiber filters (47 mm, pore
size 1.6 µm, Whatman, England), Supelclean ENVI-Florisil
(500 mg/3 mL, Sigma-Aldrich, USA) normal-phase cartridges,
and activated carbon (Merck, Darmstadt, Germany) were used
for solid-phase extraction. The general physicochemical prop-
erties of fipronil, cypermethrin, and tebuconazole are given in
Supplemental Table S1.

2. Experimental design
The field experiment was conducted in the Huong An Com-
mune, Huong Tra District, Thua Thien-Hue Province, North
Central Vietnam (Fig. 1). This province is characterized by
coastal terrain and a narrow land shape and is representative of a
typical tropical monsoon climate. The Huong An Commune is a
traditional cultivation area of green onions and mustard greens.

Fifteen days before the experiment began, an agricultural
worker removed a 20 cm topsoil layer from the study area and
replaced it with organic topsoil (pesticide free) collected from
a nonagricultural area nearby. The farmer then tilled and fertili-
zed the soil. A boundary of sugarcane was planted to protect
the study area (ca. 400 m²). Three cultivation designs were set up
for each vegetable as follows, illustrated in Fig. 1, replicating the

Fig. 1. Study field and experimental design for the dissipation study. A: Natural plot; B: Bed plot; C: Protected plot; D: Control plot; 1: Green onions; 2: Mustard greens.
cultural practices of local farmers:

- Natural plot: The whole plot is exposed to natural weather conditions without any protection, which is representative of traditional vegetable cultivation.
- Bed plot: The plot system is fenced in by transparent plastic sheets (1 m high) to protect the system from strong winds and destructive creatures such as rats or chickens, as well as to minimize soil erosion from surface runoff. The plot represents small-scale vegetable cultivation at the household level in rural areas of Vietnam.
- Protected plot: This plot is similar to the bed system, however, a movable roof made of transparent plastic sheets is added to protect the system from rain (the roof is pulled out to cover the system during rain). This cultivation design is commonly used in regions that suffer from heavy rain or fog events.

A control plot designed similarly to the natural system but without pesticide spraying, served as the blank sample for analysis. The plots were set up in separate areas within the 400 m² of the study area and were bordered by sugarcane.

Due to the difficulties that occur while conducting a study in the field (experimental area limit, protection of the designed plots, etc.), a replicate experiment was not implemented in this study. To reduce systematic errors that might occur, a completely randomized design was applied.

The experiment for this research began on June 4, 2018. Seedlings of green onions and mustard greens (10 days old) were transplanted in rows, 10 cm apart, with a density of one plant per 100 cm². In keeping with the traditional cultivation technique of local farmers, pesticides were applied at least every 10 days after transplanting. Therefore, in this study, the tested plots were sprayed on day 10, day 20, and day 30 after transplanting. Based on the dose instructions on the pesticide container labels, the corresponding amounts of Tungsten SCC (fipronil 50 g/L, 25 g a.i. (active ingredient)/ha), Appencyper 35EC (cypermethrin 35% w/w, 35 g a.i./ha), and T-SuperNew 350EC (tebuconazole 50 g/L, 15 g a.i./ha) were dissolved in two liters of water. The resulting solutions of ca. 0.053 g fipronil/L, 0.087 g cypermethrin/L and 0.030 g tebuconazole/L were sprayed on the plants within the test plots.

3. Sampling

Based on the growing cycles of green onions (45–55 days) and mustard greens (40–45 days), this study selected day 45 to harvest both of the studied vegetables, and this was the basis for setting the sampling schedule below. On the last spraying campaign (day 30 after the first pesticide application), the studied vegetable samples were collected one hour after pesticide spraying at each plot (day 0). A composite sample was taken after mixing three single sample portions (above-ground only), randomly collected at each plot, wrapped in aluminum foil, and directly cool-transported (in a foam-insulated box) to the laboratory for sample treatment and measurement. The next sampling days (after day 0) were days 1, 2, 3, 4, 5, 7, 10, and 14. Measurement of plant growth (leaf length, number of leaves, and weight) was also conducted. The detailed measurements are shown in Supplemental Table S2. Noticeably, during the dry season at the study site (normally from January to August), there had been some unpredicted rainfall events. This phenomenon was also recorded during the experimental period; specifically, a rainfall of 162 mm which occurred on day 0 (at night) and one of 12 mm which occurred on day 10 (daytime), (see Supplemental Table S3 for details).

4. Pesticide analysis

The researchers successfully developed and validated an analytical method for the quantification of multiresidue pesticides in vegetables, including fipronil, cypermethrin, and tebuconazole. After collection from the plots, the roots were removed but the plants were kept in their original state (unwashed). The samples were chopped and homogenized using a metal hand blender (HR1604, Philips, Netherlands). After that, homogenized samples (5 g) were taken. δ-HCH was added as a surrogate (100 ng). Sixty milliliters of acetone was added for ultrasonic extraction 15 min before filtration. The extraction process was repeated twice, with 20 mL of acetone each time. The total extract was evaporated to about 10 mL before submitted to solid-phase extraction (SPE) using activated carbon-packed columns with 10 mL of an acetone/toluene (1:1, v/v) elution and then using florisil cartridges with 10 mL of an acetone/n-hexane (1:5, v/v) elution. The extract was then evaporated nearly to dryness under a nitrogen flow; next, toluene was added up to 1 mL in amber vials containing 100 ng of phenanthrene-D10. The vials were stored at −20°C until measurement.

Gas chromatographic separation and detection of the target analytes was carried out using a gas chromatography-triple quadrupole mass spectrometry system (GCMS-TQ8040, Shimadzu, Japan) and an Rtx-CL pesticide capillary column (30 m × 0.25 mm, film thickness 0.25 μm, Restek, USA). The triple-quadrupole mass spectrometer was operated with multiple reaction monitoring (MRM).

5. Quality control

Green onions and mustard greens from the control plots were used as blank samples to check for laboratory contamination. The trueness and repeatability [assessed via relative standard deviation (RSD) percentage] of the analytical method were determined by conducting five replicates of blank samples fortified with 20 ng/g of the studied pesticides. The method detection limit (MDL) of each target pesticide was achieved by analyzing seven spiked mustard green samples at a level of 10 ng/g, which was then calculated as MDL = 3.14 × SD (3.14 is the one-tailed t value for a 99% confidence level with six degrees of freedom, and SD being the standard deviation of seven replicates). The quality-control results are shown in Supplemental Table S4. Simply stated, for fipronil, cypermethrin and tebuconazole, the recovery rates were 111%, 87%, and 84% respectively; the RSDs were 8.2%, 9.4%, and 9.7% respectively; and the MDLs were 1.8 μg/kg, 3.6 μg/kg, and 2.2 μg/kg respectively.
6. Dissipation model and data analysis

Pesticide-dissipation data were fitted to the exponential decay equation:

\[ C_t = C_0 \cdot e^{-kt} \]

\( C_t \): Concentration of the pesticide at time \( t \) (mg/kg); \( C_0 \): initial concentration (mg/kg); \( k \): dissipation rate constant (day\(^{-1}\)); \( t \): elapsed time (day).

The equation was obtained by applying nonlinear, least-squares regression, analyzing the concentration against time, and employing the first-order kinetic model. The goodness of fit and the quality of a given model were assessed via examination of the coefficient (R\(^2\)), the significant level (p-value) and the regression coefficient. The dissipation half-lives (DT\(_{50}\), the time required for 50% of the initial concentration to dissipate) were calculated using the following equation: DT\(_{50}\) = (ln2)/k.

Data normality and the homogeneity of variances were checked using the Shapiro-Wilk test and the Levene test, respectively. An ANOVA of data sets was performed to identify the significant-impact factor(s) affecting the dissipation of pesticides in the studied vegetables.

Sigma-Plot 11.0 (Systat Software Inc., San Jose, California, USA) and Microsoft Office Excel 2010 (Microsoft Corporation, Redmond, Washington, USA) were employed for data analysis.

Results and Discussion

Figure 2 illustrates the dissipation curves of the three pesticides in accordance with the plots.

1. Dissipation of fipronil

The raw data of the dissipation profile of fipronil in green onions and mustard greens is shown in Supplemental Table S5. Even though fipronil was applied to the experimental plots in the same concentration, the initial deposits (concentrations detected at day 0) were different among the plots, varying from 0.5629 mg/kg in the green onion bed plot to 1.3087 mg/kg in the mustard green protected plot. One day after application (day 1), fipronil dissipated by 32.1%, compared to the initial deposit on day 0, in both the green onion and mustard green protected plots. At the same time, the dissipation rate was much higher.
in the bed plots and natural plots for both tested vegetables, at 84.8–86.4%. The reason for this difference was a rain event that happened on the night after the last spraying, washing pesticides off the surfaces. Celik\(^{23}\) has already reported the high loss of pesticides due to rainfall occurring right after the application. This was also confirmed by related reports\(^{3,4}\) that rainfall contributes to a rapid decline of pesticides in vegetables. This is true regardless of the fact that fipronil is a systemic pesticide, which is easily absorbed into the tissue of the leaves after application. At the end of the experiment (day 14), fipronil had decomposed almost completely in both studied vegetables.

Fipronil dissipated exponentially with time in both tested vegetables in all plots, following the rules of first-order kinetics, in which the data variations were well explained by the regression equations (\(R^2 > 0.92, \ p < 0.0001\)), as shown in Table 1. The half-life of fipronil rose from 0.4 days (bed plot) to 1.4 days (protected plot) for green onions and from 0.4 days (natural plot) to 2.2 days (protected plot) for mustard greens. Fipronil was rather persistent in the protected systems; meanwhile, the other growing systems did not interfere with the fast dissipation of fipronil in the tested vegetables, demonstrating the remarkable impact of rain and sunlight on the dissipation of fipronil in the vegetables after spraying. In contrast, a study performed by Pei\(^{13}\) stated that the main processes affecting fipronil dissipation were oxidation and hydrolysis; fipronil was reported to have a half-life of 2.6 days in mustard greens cultivated under natural conditions.

### 2. Dissipation of cypermethrin

After application (day 0), the mean value of cypermethrin deposits in the two vegetables in three designs (\(n=6\)) was significantly higher compared than those of fipronil and tebuconazole (\(p<0.001\), one-way ANOVA). This could be due to the higher spraying dose of cypermethrin (35 g a.i./ha). Additionally, cypermethrin has special properties that make it almost insoluble in water (solubility 0.009 mg/L) and result in a high log \(K_{ow}\) (5.5) (Supplemental Table S1), facilitating a strong adsorption of cypermethrin onto the oily and fatty parts of a plant after application. One day after application, in the green onion systems, only a 1.5% decline of cypermethrin occurred in the protected plot, while a higher loss was found in the bed plots and natural plots for both vegetables (25.8–36.4%) (Supplemental Table S6).

#### Table 1. Dissipation equations and half-life time (\(DT_{50}\)) of fipronil, cypermethrin, and tebuconazole in green onions and mustard greens

| pesticide       | vegetable  | plot type         | Dissipation equation\(^{40}\) | \(R^2\) | \(DT_{50}\) (days) |
|------------------|------------|-------------------|-------------------------------|--------|-------------------|
| Fipronil         | Green onions | Protected plot    | \(C = (0.863 \pm 0.073)e^{-(0.303 \pm 0.073)t}\) | 0.989  | 1.4               |
|                  | Green onions | Bed plot          | \(C = (0.560 \pm 0.123)e^{-(1.719 \pm 1.650)t}\) | 0.921  | 0.4               |
|                  | Green onions | Natural plot      | \(C = (0.562 \pm 0.111)e^{-(1.487 \pm 0.807)t}\) | 0.938  | 0.5               |
|                  | Mustard greens | Protected plot   | \(C = (1.241 \pm 0.166)e^{-(0.310 \pm 0.077)t}\) | 0.965  | 2.2               |
|                  | Mustard greens | Bed plot         | \(C = (1.054 \pm 0.019)e^{-(0.824 \pm 0.073)t}\) | 0.997  | 0.8               |
|                  | Mustard greens | Natural plot     | \(C = (0.823 \pm 0.045)e^{-(1.310 \pm 0.371)t}\) | 0.974  | 0.4               |
|                  | Cypermethrin  | Green onions      | Protected plot                | \(C = (7.240 \pm 0.951)e^{-(0.116 \pm 0.037)t}\) | 0.921  | 6                 |
|                  | Green onions | Bed plot          | \(C = (5.159 \pm 0.555)e^{-(0.159 \pm 0.037)t}\) | 0.962  | 4.4               |
|                  | Green onions | Natural plot      | \(C = (5.376 \pm 0.669)e^{-(0.223 \pm 0.055)t}\) | 0.962  | 3                 |
|                  | Mustard greens | Protected plot   | \(C = (6.003 \pm 0.363)e^{-(0.209 \pm 0.025)t}\) | 0.991  | 3.3               |
|                  | Mustard greens | Bed plot         | \(C = (4.518 \pm 0.437)e^{-(0.279 \pm 0.023)t}\) | 0.982  | 2.5               |
|                  | Mustard greens | Natural plot     | \(C = (4.959 \pm 0.219)e^{-(0.352 \pm 0.067)t}\) | 0.981  | 2                 |
|                  | Tebuconazole  | Green onions      | Protected plot                | \(C = (0.362 \pm 0.067)e^{-(0.210 \pm 0.074)t}\) | 0.928  | 3.3               |
|                  | Green onions | Bed plot          | \(C = (0.341 \pm 0.098)e^{-(0.372 \pm 0.308)t}\) | 0.888  | 1.2               |
|                  | Green onions | Natural plot      | \(C = (0.304 \pm 0.072)e^{-(0.510 \pm 0.222)t}\) | 0.921  | 1.4               |
|                  | Mustard greens | Protected plot   | \(C = (0.875 \pm 0.131)e^{-(0.242 \pm 0.070)t}\) | 0.947  | 2.9               |
|                  | Mustard greens | Bed plot         | \(C = (0.870 \pm 0.106)e^{-(0.312 \pm 0.070)t}\) | 0.973  | 2.2               |
|                  | Mustard greens | Natural plot     | \(C = (0.955 \pm 0.150)e^{-(0.801 \pm 0.255)t}\) | 0.961  | 0.9               |

\(^{40}\) \(C\): The concentration of pesticide at time \(t\) (mg/kg); \(C_0\): the initial concentration (mg/kg); \(t\): the elapsed time (day); \(k\): the dissipation rate constant (day\(^{-1}\)); \(\varepsilon\): the 95% confidence limit (mg/kg). The \(p\)-values for the equations in the table are all \(<0.0001\).
rainfall on the night of the last application, as explained above, in Section 3.1., was responsible for this difference. Accordingly, at the end of the experiment (day 14), 88.1–99.3% of cypermethrin had decomposed in the two vegetables in the tested plots, except for the green onions in the protected plot (69.4% dissipation).

The dissipation data of cypermethrin were well documented by first-order kinetics for the studied vegetables in the three plots (R²>0.92, p<0.0001) (Table 1 and Fig. 2). The half-lives of cypermethrin were longer than those of fipronil, varying from 2–3 days (in mustard greens) to 3–6 days (in green onions) for the experimental plots. A study from Chai (25) reported half-lives (DT₅₀) of cypermethrin in mustard greens that fluctuated from 1.6 to 2.5 days at different experimental locations in Malaysia. Meanwhile, Zhang (26) reported DT₅₀s of cypermethrin ranging from 2.3 to 4.8 days in spring cabbage grown in open fields in China. The dissipation of cypermethrin has also been tested on other vegetables; for instance, in Nath’s work in India, (15) the DT₅₀ of cypermethrin was 4.1 days in the okra fruit. Ripley (10) reported that the half-life values of cypermethrin varied from 2.6 to 3.5 days in different crops cultivated in Canada, with different spraying dosages. These results are comparable with the findings in the current study in terms of the bed and natural systems, suggesting that climate conditions were unlikely to be the primary factor responsible for the persistence of cypermethrin in vegetables.

3. Dissipation of tebuconazole

Tebuconazole has a lower spraying dose (15 g a.i./ha) than fipronil (25 g a.i./ha) and cypermethrin (35 g a.i./ha). Consequently, the deposits of tebuconazole on plants were recorded at considerably lower levels, fluctuating from 0.282–0.338 mg/kg in green onions to 0.832–0.983 mg/kg in mustard greens for the three cropping designs (Supplemental Table S7). However, similar to the dissipation patterns of fipronil and cypermethrin, that of tebuconazole was more persistent in the protected plots than in the systems exposed to natural conditions, regardless the fact that it also is a systemic pesticide. Over 99% of tebuconazole had dissipated after 14 days in the bed plots and natural plots of both green onions and mustard greens.

The tebuconazole dissipation followed first-order kinetics (R²>0.89) for both vegetables in all plots (Table 1). The calculated half-life values for tebuconazole in the green onion test systems were 3.3 days (protected), 1.2 days (bed) and 1.4 days (natural). In the mustard green systems, the values were 2.9 days (protected), 2.2 days (bed) and 0.9 days (natural). In the study of Litoriya (27) in India, the DT₅₀ values for tebuconazole in cowpeas were 2.3 and 2.4 days at standard and double spraying doses, respectively. In contrast, the pesticide was reported to be more persistent in pomegranate fruit cultivated in India, in which the half-lives of tebuconazole were 4.7 and 5.4 days at two different application doses. (12)

4. Comparison of the Pesticide-Dissipation Rate

The difference in the obtained C₀ values of the exponential equations shown in Table 1 implies the significant effects of other factors (sunlight, wind, humidity, etc.) that contributed to the random errors of the dissipation rate constants (k). Therefore, to understand the degradation behaviors of the studied pesticides in the two vegetables with three different cropping designs (accepting random fluctuation caused by other factors), an ANOVA was applied to the k values in the obtained regression equations (Supplemental Table S8). The expectation was to define what is/are the significant impact factor(s) in the dissipation of pesticides in the studied vegetables.

Normality and homogeneity of variances for the k data of groups/samples in the ANOVA were satisfied with all p-values >0.05 using the Shapiro–Wilk test and the Levene test, respectively. The three-factor ANOVA (factor A—vegetable; factor B—cropping design; factor C—pesticide) without replication takes into account the interactions between the factors and demonstrates two main findings, as shown in Table 2. First, it is noted that neither the interaction of factors nor the type of vegetable affected the dissipation of pesticides (with p=0.11 to 0.39 and p=0.71, respectively); the latter implies that the degradation rate of each pesticide was similar in every tested vegetable. Second, there were significant differences between cropping designs (p=0.02) and between studied pesticides (p=0.005). For example, the dissipation of a pesticide could be manipulated by changing the cropping design and physicochemical properties.

| Table 2. Three factor ANOVA without replication, considering the interaction effects of factors° |
|-----------------|-----|-------|-----|-----------------|------------|------|
| SS              | df  | MS    | F   | p-value         | sig       |
| A               | 0.00726 | 1 | 0.00726 | 0.156284 | 0.712778 | no  |
| B               | 1.101995 | 2 | 0.550997 | 11.86095 | 0.02082 | yes |
| C               | 2.555126 | 2 | 1.277563 | 27.50123 | 0.004596 | yes |
| A×B             | 0.264455 | 2 | 0.132228 | 2.846377 | 0.170304 | no  |
| A×C             | 0.110115 | 2 | 0.053058 | 1.185189 | 0.394266 | no  |
| B×C             | 0.720725 | 4 | 0.180181 | 3.878642 | 0.10882 | no  |
| Within          | 0.185819 | 4 | 0.046455 |                |            |      |
| Total           | 4.945496 | 17 | 0.290912 |                |            |      |

° SS: Sum of square; df: degree of freedom; MS: mean of square; F value: variance ratio; sig: significant. A: Vegetables; B: cropping designs; C: pesticides.
Based on these results, an ANOVA follow-up analysis (using the Tukey HSD test) was conducted for factor B (cropping design) and factor C (pesticide) to gain insight into the specific differences. The results indicated that, in the case of cropping designs, the k mean of the natural plot (0.864±0.646 day⁻¹, n=6) was significantly higher than that of the protected plot (0.265±0.132 day⁻¹, n=6) with p=0.02, suggesting that a roof over a plot facilitates the long persistence of pesticides in plants. Thus, rainfall and sunlight can be considered important conditions for promoting the rapid degradation of pesticides in vegetables. This finding is consistent with the results discussed in sections 3.1., 3.2., and 3.3. In terms of the pesticide factor, the follow-up analysis discovered a significantly higher k mean with fipronil (1.109±0.647 day⁻¹, n=6) than with cypermethrin (0.223±0.084 day⁻¹, n=6), with p=0.005, and with tebuconazole (0.441±0.229 day⁻¹, n=6) with p=0.013, implying that fipronil was less persistent in plants than cypermethrin and tebuconazole. This finding could be explained by the fact that fipronil is the fastest photosynthetic decomposition compound (aqueous photolysis DT₅₀ of only 0.33 days, Suplemental Table S1). Since this experiment was conducted in a tropical climate during summer, sunshine played an important role in the degradation process of photolysis-sensitive compounds such as fipronil. Meanwhile, the degradation rates of cypermethrin and tebuconazole are quite similar (p=0.29). Given that the physicochemical properties of cypermethrin and tebuconazole are quite different, it is worth noting that the biochemical nature also contributes to the degradation of a compound in a plant, which is not the focus of this study. It is therefore recommended that scientists conduct further studies on the biodegradation mechanism of these compounds for a more comprehensive understanding of the dissipation of these pesticides.

**Conclusion**

The dissipation of fipronil, cypermethrin, and tebuconazole in both green onions and mustard greens followed first-order kinetics; as such, the half-lives of fipronil fluctuated from 0.4 to 2.2 days, those of cypermethrin from 2.0 to 6.0 days, and those of tebuconazole from 0.9 to 3.3 days,varying among cultivation regimes.

Additionally, researchers came to the conclusion that the degradation rate of the studied pesticides in vegetables was affected mainly by two factors: the cropping regimes and the pesticide’s physicochemical properties. The roof cover of the protected plot helped to reduce pesticide loss (i.e., promoted the long persistence of pesticides in plants). Fipronil tended to dissipate faster in plants than either cypermethrin or tebuconazole. The dissipation data obtained from this study can serve as a reference for pesticide-risk assessment, especially for the regulatory authority in setting maximum residue levels (MRLs) for the studied pesticides in mustard greens and green onions. Further fate studies under different seasons, such as summer and winter, are recommended to understand the specific influence of natural conditions. Further investigation of the biodegradation mechanism of pesticides should also be conducted due to the possible impact of biochemical nature.

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