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Original Article

Comparative efficacy and residue dynamics of three insecticides against *Thrips tabaci* in onion using foliar spray and drip chemigation

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Abstract

Onion (*Allium cepa* L.) is a globally significant vegetable crop that is frequently targeted by various insect pests including the onion thrips, *Thrips tabaci* Lindeman. This study evaluated the efficacy of three insecticides – dinotefuran, flonicamid, and flometoquin – against adult *T. tabaci* on onion using two application methods: drip chemigation and foliar application. Additionally, the study assessed residues of the three insecticides in green onions and onion bulbs, as well as plant growth and productivity response to the insecticides. The results showed that flometoquin, flonicamid and dinotefuran have effectively controlled *A. cepa* infestations after foliar application. However, flometoquin chemigation maintained effective control for 45 days after application. The findings indicated that the tested insecticides did not significantly impact plant height or leaf number; however, the foliar application of flometoquin resulted in the highest mean bulb weight and overall crop yield per m^2, while the drip chemigation method produced the highest chloroplast density in plant cells. Flonicamid and dinotefuran exhibited prolonged persistence with residues detectable up to 45 d post-chemigation. Additionally, High-Performance Liquid Chromatography (HPLC) was used as the primary technique for residue determination of flonicamid, flometoquin and dinotefuran with retention time 3.8, 4.54 and 4.9 min. the LOQ of tested pesticides were 0.1 mg/kg. While Maximum Residue Limit (MRL) of flonicamid**,** flometoquin and dinotefuran was 0.03, 0.05 and 0.1 mg/kg. The half-lives of flonicamid were 2.28 and 4.16 d and the pre-harvest intervals (PHI) were 5 and 10 d for spraying and chemigation, respectively. Flometoquin had a half-life of 3.03 d after spraying, with a PHI of 10 d. Dinotefuran's half-lives were 3.34 and 2.17 d, with PHIs of 15 and 10 d in green onions following spraying and chemigation, respectively. Our results suggest that drip chemigation with dinotefuran and flonicamid represents a promising and cost-effective strategy for the sustainable management of onion thrips.

Keywords: Onion thrips, Insecticide efficacy, Foliar application, Drip chemigation, Insecticide residue

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Introduction

Onion (*Allium cepa* L.) is one of the most important vegetable crops in the world (Galsurker et al., 2017), with 600 to 920 species harvested annually worldwide (Zhao et al., 2021). In Egypt, green and dry onions are important foods and have been cultivated for export since 2016, producing around 8.6 million tons of onion annually (Ahmed et al., 2019). The onion is a vegetable with culinary, medicinal, and nutritional benefits (Ouedraogo et al., 2015). It contains diverse phytochemicals including; organosulfur compounds, phenolic compounds, polysaccharides and saponins, which are the major bioactive constituents of onion (Zhao et al., 2021). Nutritionally, it is an integral part of energetic, protective and supportive diets because it contains vitamins, minerals, lipids, proteins, carbs, essential oils, acids, and organic fibers (Donkor et al., 2016; Konate et al., 2017; Dakuyo et al., 2020).

Numerous pests attack this crop, with onion thrips (*T. tabaci* Lindeman) being the most prevalent once being described by (Vélez et al., 2020; Iglesias et al., 2021; Pobożniak et al., 2022). Adults and larvae of onion thrips rasp and rub the plant surface, which causes direct damage by feeding on plant tissues, leading to silvering, curling and stunted growth. Additionally, the insect then sips up the exuded sap, i.e., the content of epidermal and mesophyll cells (Chisholm and Lewis, 1984), thus affecting photosynthesis and ultimately crop yield (Gao et al., 2020). Moreover, it acts as a vector for several plant viruses including Iris yellow spot virus (IYSV), posing a serious threat to crop productivity and quality (Pappu et al., 2009).

Although conventional pesticide residues have led to the development of insect resistance and reducing their long-term efficacy in addition with accumulate in the environment and the edible plant (Vryzas, 2018; Vélez et al., 2020) and pose risks to human health, pesticides have been used to protect crops from pests (Jallow et al., 2017). In recent years, several novel insecticides have been developed to overcome resistance and minimize environmental impact. New chemical pesticides are required to overcome the problems of residues and resistance (Moustafa et al., 2023; El-Hefny et al., 2024). Therefore, dinotefuran, flonicamid and flometoquin insecticides have been employed to combat biting and sucking insects because of their improved pest control capabilities and favorable toxicological, environmental and ecotoxicological profiles.

The mode of action of the new pyridine amide pesticide, flonicamid, is prevention of pests from sucking from host plants by disrupting their feeding behavior. Moreover, flonicamid shows no cross-resistance to other pesticides like pyrethroid and neonicotinoid insecticides and is a safe pesticide with low toxicity to fish and natural enemies (Moustafa et al., 2024). Flonicamid is characterized by high internal absorption, extended duration, low toxicity, and high efficiency. Aphids and other piercing-sucking pests could be managed in vegetables, fruit, tea, grains, and oil crops due to the mode of action (Moustafa et al., 2024). When applying flonicamid in vegetable protection areas pollinated by honeybees, caution should be exercised because it presents some dangers to honeybees (Sahu et al., 2020; Zhang et al., 2022). The third-generation nicotinic insecticide, dinotefuran, has superior systemic, osmotic action, and broad insecticidal spectrum qualities (Wakita et al., 2003). It generally affects the insect acetylcholine receptors (AChR) by inhibiting regular neurotransmission. Moreover, dinotefuran is relatively harmless due to its low toxicity to mammals (Ham et al., 2022). Dinotefuran can be sprayed, soaked, broadcasted, and prick-in-hole treated on foliage, soil, nurseries, and paddy water (Zhang et al., 2022). Flometoquin is an insecticide with a novel phenoxy-quinoline structure. It has potent and rapid insecticidal activity against a range of thrip species in the nymphal and adult stages, potentially reducing crop damage and loss caused by insect pest species (Kobayashi et al., 2023). Furthermore, flometoquin is safe for non-target arthropods, making it an excellent option for managing insect pests in integrated pest management (IPM) programs (Kobayashi et al., 2023).

Consequently, the pre-harvest interval (PHI) determination for each insecticide involves evaluating several factors related to the chemical properties of the insecticide, including its behavior in the environment and interaction with different crops. As a result, field tests evaluate how pesticide residues break down over time on various crops and how quickly the residual levels drop to safe levels. Therefore, this study was undertaken to 1) evaluate the efficacy of flonicamid, flometoquin, and dinotefuran applied by chemigation and foliar spraying against *T. tabaci* adults on onions, 2) determine the residue of each on green leaves and onion bulbs, and 3) assess the impact of insecticide application on selected plant growth parameters (e.g., plant height and number of leaves) and yield (bulb weight and total yield).

Material and Methods

Insecticides and chemicals
The three tested insecticides, their formulations, and application rates are listed in Table-1. The insecticide standards were purchased from Dr. Ehrenstorfer (Augsburg, Germany), with a purity ≥ 98%. A 1000 µg/mL stock solution was used to prepare further concentrations ranging from 0.01 to 10.0 µg/ml. The chemicals and solvents used in the residue analysis were obtained from the Merck Company (Darmstadt, Germany).

Table-1. The tested insecticides, their formulations, and application rates.

Common name	Trade name	Formulation	Company	Rate of Foliar application (g a.i. /ha)	Rate of Chemigation (g a.i. /ha)
Dinotefuran	Rapator	20% SG	Habi Fung Biochemical LTD-China	71	286
Flonicamid	Up-stage	50% WG	Anhuisida pesticide Chemicals Co., LTD-China	60	238
Flometoquin	Kajura	10% SC	Nippon Kayaku Co., LTD-Japan	48	190

a.i.= active ingredient

Field study
The study was conducted at the Faculty of Agriculture Farm (Giza, Egypt) during two consecutive winter growing seasons (2022 and 2023). Seedlings of a commercial cv. (Giza 20) were cultivated, and plants were maintained following agricultural practices to ensure crop health and productivity. Seedlings were planted in rows with shallow furrows along the ridge. The distance between seedlings was 7-10 cm, and each experimental plot contained 50 plants. During soil preparation, the recommended amounts of potassium (119.0 kg/10.000 m^2) as potassium sulfate [48% K_2SO_4]), phosphorus (107.1 kg/10.000 m^2) as calcium superphosphate [15.5% P_2O_5]) and aged cattle dung were broadcast. Following transplantation, two applications (426.0 kg each) of nitrogen (285.6 kg/10.000 m^2) in the form of ammonium nitrate (33.5% N; 852.0 kg/10.000 m^2) were made (El-Shaikh et al., 2021). The first was applied at the initial irrigation (25 days after transplanting) and the second 30 days later. The randomized complete block design was used, with three replications in each experiment.

The experiments began at winter season on 5 February 2022 and on 10 February 2023, when the onion plants were 50 days into their growth. For chemigation, soil treatment was pumped from a 21.21-L polyethylene mixing bottle using a 0.51-metric horsepower pump, delivering 12 L of solution every 30 min into the predetermined sub-main line controlled by a valve at the manifold. Each sub-main mixed only one treatment at a time with the irrigation water. All chemigation treatments were injected in 10 L solution over about 22 min, followed by 15 L of clean water rinse. Plants were irrigated for about 70 min before and after the injection. The insecticide was applied using a Solo Dossal sprayer motor (20-L capacity) at the recommended application rate for foliar application.

Twenty-five onion plants from each replicate were randomly selected and transported to the laboratory, where they were individually examined. Each treatment has 4 replicates. Applications were initiated when 3-5 adult thrips were found on a randomly selected plant. Numbers of adults were counted and recorded immediately before treatment, 1 d (initial kill) and 3, 5, 7, 10, 15, 21, 35 and 45 d after application (Moustafa et al., 2022) to assess the residual effect according to (Henderson and Tilton, 1955).

Plant growth parameters
Plant height was measured from the ground surface to the tip of the longest leaf for 20 randomly selected plants per plot to calculate the mean plant height at each sampling time. The numbers of completely developed functional leaves on each of 20 randomly selected plants were counted at 45 and 90 d after planting to calculate the mean number of leaves per plant on those dates. At maturity (e.g., >75% of bulb

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necks lodging), all plants were uprooted and weighed after removing the dry leaves to calculate the total yield/m^2 in each plot. The mean bulb weight was calculated by dividing the total weight of the onion bulbs in each plot by the number of bulbs.

Plant chloroplast density

Transmission electron microscopy (TEM) was used to examine the density of chloroplast ultrastructure in onion leaf cells following insecticide applications. Eight samples in total were examined. These were leaf tissue from plants 45 d after planting and before insecticide application (A), plants after foliar application (B) and chemigation (G) of flometoquin, plants after foliar application (C) and chemigation (D) of flonicamid, plants after foliar application (E) and chemigation (F) of dinotefuran, and control plant without insecticide at 90 d after planting. Sampled plant tissue consisted of 1 mm sections of the plant. After being fixed in 2.5% glutaraldehyde made with 0.1 M sodium cacodylate buffer and osmium tetroxide, these tissue slices were dried in alcohol, embedded in an epoxy resin (Electron Microscopy Sciences, Hatfield, PA, USA), and polymerized for 48 hours at 60°C. Using glass knives and a Leica Ultracut UCT ultramicrotome, semi-thin slices were cut to a thickness of approximately 0.5-1 µm. They were then stained with 1% toluidine blue in 1% borax to facilitate the selection of appropriate tissue areas before TEM analysis. Ultrathin sections (75–90 nm thick), collected on 300-mesh copper grids, were contrast-stained with uranyl acetate and lead citrate. A JEM-1400 transmission electron microscope (JEOL, Tokyo, Japan) operating at 80 kV was used to examine the slices. A side-mounted CCD digital camera (AMT Optronics, 1632 × 1632-pixel format) was used to take pictures. TEM was carried out at Cairo University-Research Park, Faculty of Agriculture's FARP TEM facility (Hanker and Giammara, 1993).

Validation, extraction and determination

The method has been validated using SANTE/2020/12830 for estimating the residues of dinotefuran, flonicamid, and flometoquin in green onions and onion bulbs. It has been assessed based on parameters like linearity, precision, repeatability, matrix effect, limit of detection (LOD), and limit of quantification (LOQ).

Extracting organic compounds from food and ecological matrices is complicated and time-consuming. However, the QuEChERS method (quick, easy, cheap, effective, rugged, and safe), which minimizes the number of steps and uses smaller amounts of reagents with high recovery rates, was performed using the protocol of (Anastassiades et al., 2003).

Plant samples were submitted to HPLC-DAD using an Agilent 1260 series HPLC system from Agilent Technologies (Santa Clara, USA) equipped with an analytical column (Nucleosil C18) measuring 30 mm by 4.6 mm id x 5 m, a variable wavelength diode array detector (DAD-G1315D), and a quaternary pump (G1311B). Table-2 displays the mobile phase flow rate, the detection wavelength, and the retention duration.

Table-2. The mobile phase, flow rate, wavelength, and retention time for flonicamid, flometoquin, and dinotefuran detection using HPLC-DAD.

Insecticide	Mobile phase	Flow rate	Wavelength	Retention time
Flonicamid	Acetonitrile 90% + water 10%	0.8 ml/min	205 nm	3.8 min
Flometoquin	Acetonitrile 90% + water 10%	0.8 ml/min	254 nm	4.54 min
Dinotefuran	Acetonitrile 80% + Methanol 20%	0.5 ml/min	270 nm	4.9 min

Dietary Risk Assessment (DRA)

The acceptable daily intake percentage (ADI%) was utilized to determine the risk associated with chronic dietary consumption of each pesticide with residue exceeding the MRL: NEDI = (APR x DFC) / bw, where NEDI = national estimated daily intake (mg/kg/day), APR = average pesticide residue (mg/kg), DFC = daily food consumption (kg), and bw = body weight (kg). Daily intake percentage (ADI%) was calculated as % ADI = (NEDI / ADI) x 100. A risk is considered acceptable when the % ADI is <100%; an unacceptable risk is indicated when it is >100%. As a result, anytime the % ADI amount is low, the risk is low (El Masry et al., 2024).

Statistical analyses

Analysis of variance was used to evaluate the thrip's reaction to the treatments using Minitab software (version 14.0) and the statistical program SPSS (version 22). The continuous variables were checked for normality using the Shapiro-Wilk and Kolmogorov-Smirnov tests. The data were initially examined to determine whether they met the assumptions of parametric testing. The arcsine square root was used to convert percentage values. Tukey's pairwise comparison was used for the post hoc analysis, and P-values were deemed significant at less than 0.05. Finally, R Studio (version 2022.02.4) was used to visualize the data.

Pesticide residue dissipation kinetics in onions was determined by comparing the residue concentration with the time elapsed from application. Equations that best matched the curve and had the highest coefficients of determination (R2) were identified. The dissipation of pesticide residues in onions was found to follow exponential relationships consistent with the general first-order kinetics equation Ct=C0e-kt, where C0 = the initial deposits after treatment, Ct = pesticide residue concentration at the time of t, and k = the constant rate of pesticide dissipation every day. Insecticide dissipation half-life periods were calculated using the formula RL_{50} = ln 2/k.

Results

Field efficacy

Statistically significant differences in *T. tabaci* numbers were observed among the insecticide treatments from Day 1 through Day 45 (Figure-1). In addition, thrip densities were significantly higher (*P*<0.05) in the control than in treatments with either foliar or chemigation applications from Day 1 through Day 45. We observed a significantly greater reduction in the density of adult thrips following foliar sprays of flonicamid from Day 1 through Day 45 than did its application by chemigation. Numbers of thrips on the plants reflected this with a significantly (*P*<0.05) higher number on Day 3 through Day 45 following application by chemigation than with foliar application. Foliar application of flometoquin was more effective than chemigation in reducing thrip density. The foliar application of flometoquin, flonicamid, and Dinotefuran effectively controlled onion thrip infestations for about 35 days except for flometoquin. However, flometoquin chemigation maintained effective control for 45 days after treatment. Flonicamid and dinotefuran chemigation effectively controlled onion thrips for 45 days in both seasons. However, flometoquin chemigation gave poor control. Thus, the effective control period via chemigation was much longer than that of foliar application with flonicamid and dinotefuran.

Onion vegetative growth parameters

Table-3 shows the effect of insecticide treatments via chemigation and foliar application on vegetative growth, average bulb weight, and total yield of onion plants. Non-significant effects on plant height were detected at 45 days for chemigation in the two seasons in all treatments except for flonicamid. However, a significant difference (*P*<0.05) was observed after treatment with dinotefuran and flonicamid at 90 days. Regarding foliar application, all treatments except dinotefuran showed a significant difference (*P*<0.05) in plant height at both 45 and 90 days in both seasons (Table 3). Additionally, chemigation of all tested insecticides showed no significant difference (*P*<0.05) in the number of leaves at 45 and 90 days in both seasons, while foliar application significantly affected the number of leaves, as shown in Table 3. Moreover, flonicamid chemigation recorded significantly (*P*<0.05) the highest average bulb weight in 2022 and 2023 (127.80 and 129.30 g, respectively) and was associated with the highest total yield (6390 and 6463 g/m^2, respectively). In contrast, the foliar application of flometoquin resulted significantly (*P*<0.05) in the highest average bulb weight in 2022 and 2023 (138.4-141.2 g, respectively) and was associated with the highest total yield in both seasons (6922-7060 g/m^2, respectively) (Table 3).

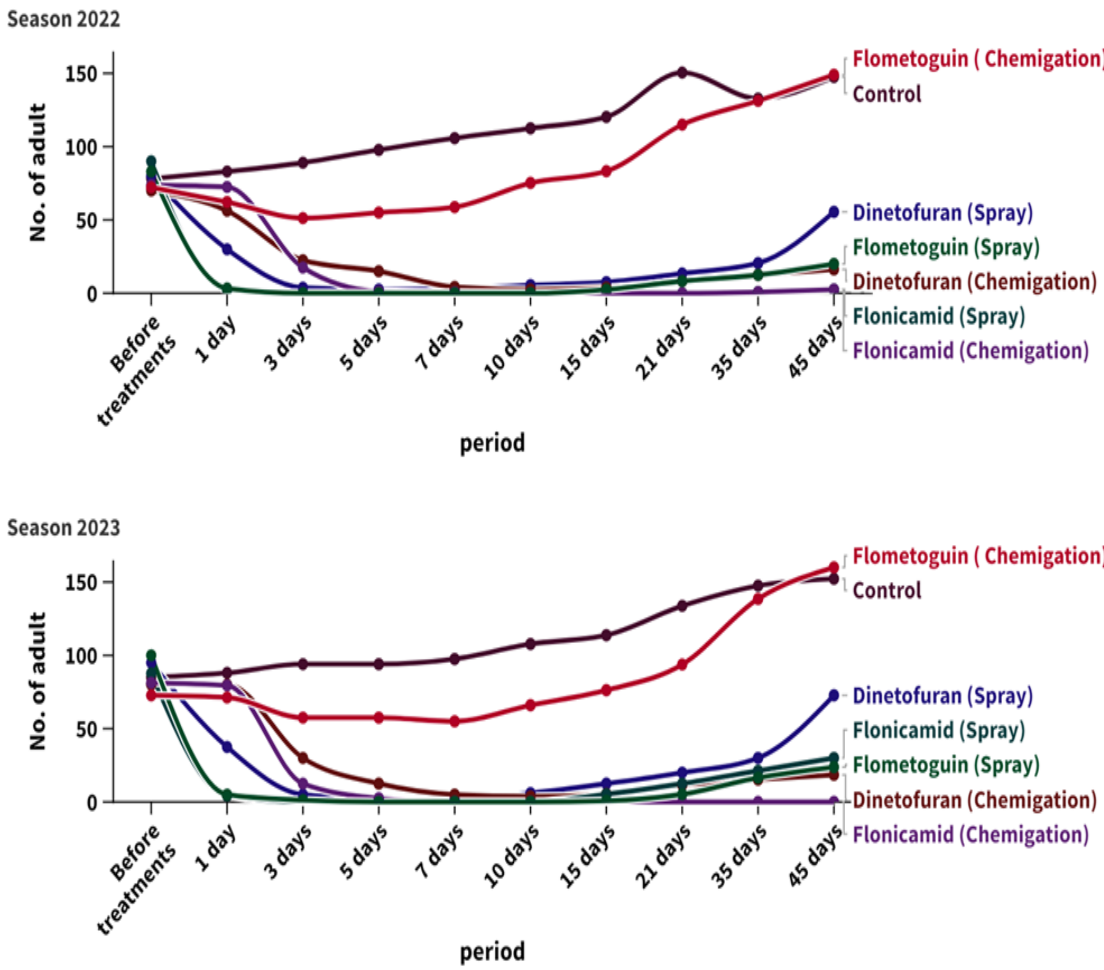

Figure-1. Mean number of *T. tabaci* adults on onion plants after field application of dinetofuran, flonicamid, and flometoquin.

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Table-3. Effect (mean ± SE) of insecticide treatments via chemigation and foliar application on vegetative growth, average bulb weight, and total yield of onion plants.

	Plant height (cm) 45 DAP		Number of leaves 45 DAP		Plant height (cm) 90 DAP		Number of leaves 90 DAP		Bulb Weight (g)		Total yield (g) /m^2	
Chemigation												
Treatment	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Dinotefuran	65.43 ±0.84b	64.89 ±0.34b	6.87 ±0.26a	6.50 ±0.28ab	70.93 ±0.47b	68.83 ±0.44b	9.31 ±0.28b	10.20 ±0.12b	112.7 ±1.21b	110.20 ±0.43b	5633 ±60.64b	5512 ±21.66b
Flonicamid	69.33 ±1.26a	67.64 ±0.37a	6.79 ±0.21a	6.75 ±0.14a	80.61 ±0.82a	77.12 ±1.09a	11.58 ±0.08a	12.20 ±0.11a	127.8 ±1.26a	129.30 ±1.26a	6390 ±63.31a	6463 ±63.33a
Flometoquin	66.19 ±0.99b	64.32 ±0.41b	6.80 ±0a	6.88 ±0.06a	68.40 ±0.1c	66.08 ±0.04c	8.53 ±0.13b	8.60 ±0.30c	99.93 ±0.17c	98.10 ±0.55c	4997 ±8.81c	4905 ±27.53c
control	65.73 ±0.37b	63.58 ±0.54b	6.57 ±0.23a	6.07 ±0.17b	67.30 ±0.29c	64.85 ±0.27c	7.57 ±0.23c	7.50 ±0.28d	73.10 ±1.41d	70.60 ±0.37d	3655 ±70.76d	3530 ±18.92d
LSD$_{5\%}$	3.00	1.60	0.72	0.67	1.86	2.22	0.80	0.71	4.28	2.43	214.20	121.30
Foliar application												
	Plant height (cm) 45 DAP		Number of leaves 45 DAP		Plant height (cm) 90 DAP		Number of leaves 90 DAP		Average Bulb Weight (g)		Total yield (g) /m^2	
Treatment	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Dinotefuran	64.23 ±0.50c	64.18 ±0.60c	6.83 ±0.16a	6.98 ±0.36a	68.96 ±0.39c	67.08 ±0.06c	8.44 ±0.15c	9.37 ±0.12c	106.5 ±0.48c	105.1 ±0.28c	5327 ±24.03c	5253 ±14.24c
Flonicamid	69.27 ±0.17a	69.63 ±0.61a	6.70 ±0.24a	6.47 ±0.24a	74.05 ±0.57b	71.80 ±0.25b	11.08 ±0.16b	11.13 ±0.24b	119.2 ±0.65b	119.9 ±0.81b	5962 ±32.44b	5997 ±40.44b
Flometoquin	69.18 ±0.19a	67.57 ±1.46ab	6.87 ±0.52a	6.67 ±0.06a	90.96 ±0.58a	90.53 ±0.77a	13.17 ±0.22a	13.77 ±0.14a	138.4 ±1.46a	141.2 ±0.80a	6922 ±73.27a	7060 ±40.41a
control	65.33 ±0.33b	64.88 ±0.32bc	6.57 ±0.29a	6.53 ±0.14a	66.70 ±0.20d	65.67 ±0.33c	7.17 ±0.40d	7.03 ±0.03d	70.67 ±1.20d	71.10 ±0.72d	3533 ±60.09d	3555 ±36.05d
LSD$_{5\%}$	1.04	3.06	1.30	0.90	1.62	1.50	0.49	0.55	3.35	2.09	167.50	104.60

DAP: Days after planting; ABW: Average bulb weight; plant height and number of leaves: at 45 DAP (before applying insecticides) and at 90 DAP (after applying insecticides).

*Means in a column that do not share a letter are significantly different

Ultrastructure of onion leaves' chloroplast imaged by TEM

The density of chloroplast in the cells of onion leaves infested with *T. tabaci* was examined by TEM image, as shown in Figure 2. Flometoquin foliar application gave the highest density of chloroplast compared to the control at 45 DAP followed by flonicamid chemigation and flonicamid foliar application. In contrast, flometoquin chemigation recorded the lowest density of chloroplast.

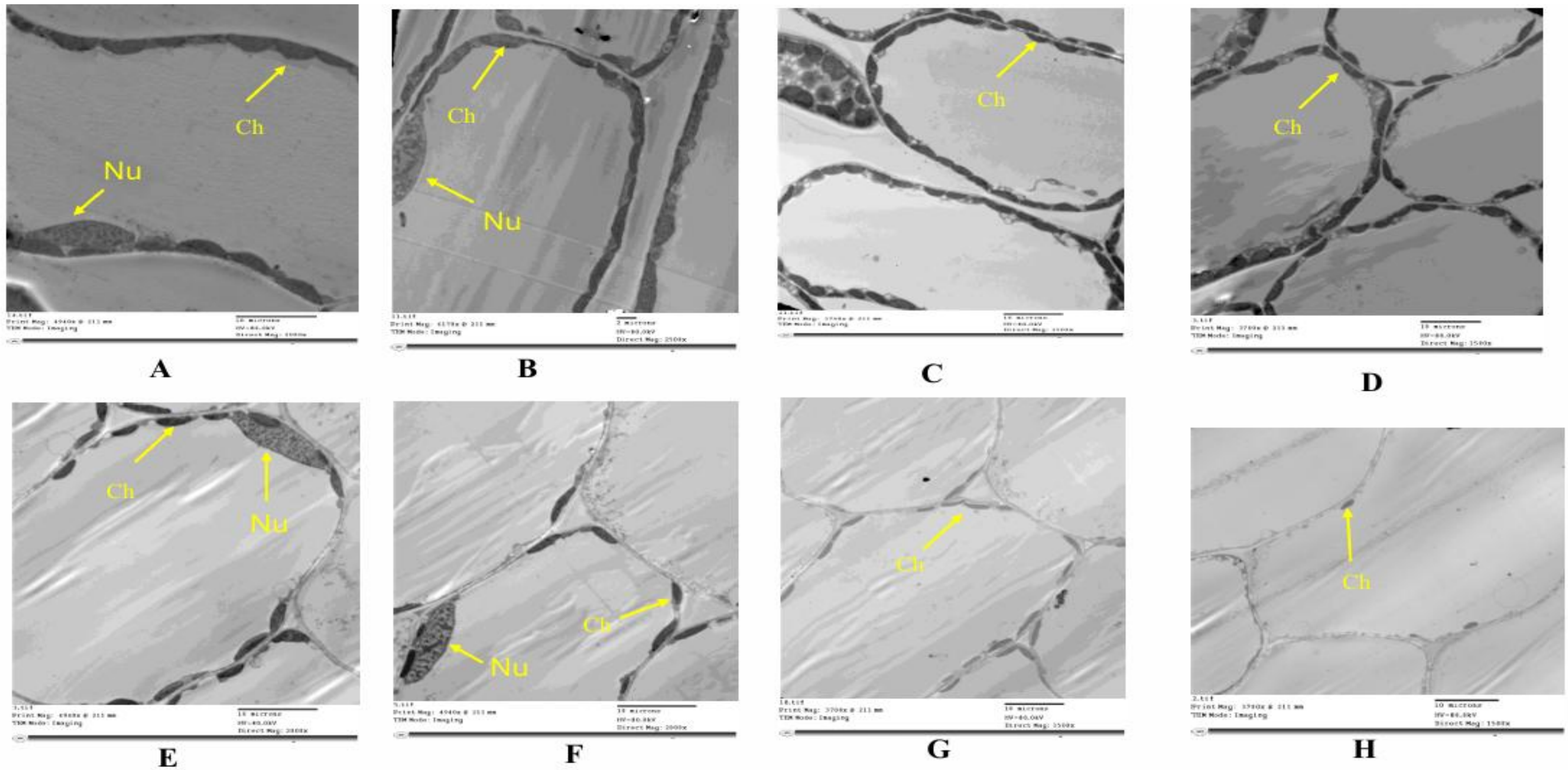

Figure-2. The ultrastructure of onion leaves' chloroplast imaged by transmission electron microscopy before and after field application of dinotefuran, flonicamid, and flometoquin. via chemigation or foliar spraying during the 2022 and 2023 seasons.
A: leaf cells at 45 DAP before application of insecticides; B: leaf cells in Flometoquin foliar application; C: leaf cells in Flonicamid chemigation; D: leaf cells in Flonicamid foliar application; E: leaf cells in Dinotefuran chemigation; F: leaf cells in Dinotefuran foliar application; G: leaf cells in Flometoquin chemigation and H: leaf cells in control at 90 DAP without using insecticides. Ch: chloroplast; Nu: Nucleus.

Insecticide residue analysis

Validation study

The results showed that the matrix effects of the tested insecticides ranged from 18.77% to 15.12%. In addition, the LOD and LOQ ranged from 0.01 to 0.1 mg/kg. Thus, the linearity of the method was established, and the calibration curves were generated from triple injections (n = 3) for each tested concentration, which ranged from 0.01 to 10.0 mg/kg. To evaluate the method's accuracy, three levels of the tested insecticide standards, ranging from 0.01 to 1.0 mg/kg, were applied to blank samples. Five replicates (n = 5) were conducted on the fortified samples, and the accuracy was evaluated by calculating the average recovery of the measured values.

The relative standard deviation (% RSD), the ratio of the standard deviation to the average concentration, is recognized as a measure of precision. Accuracy was determined by calculating the percentage difference between the known and measured concentrations. Residues from the spiked control samples were measured, demonstrating the method's reliability, accuracy, and precision for analyzing flonicamid, flometoquin, and dinotefuran. All calculated mean recoveries ranged from 90.43% to 106.5% for green onions and 88.39% to 105.31% for onion bulbs, with a % RSD ≤ 20%.

Dissipation of the tested insecticides in green and bulb onions

Dissipation of flonicamid

Data in Table 4 showed that the initial flonicamid deposit on green onion was 1.19 mg kg-1 (with RSD ±3.52%) two hours after spraying. This residue gradually decreased over sampling intervals. Flonicamid residue decreased by 14.28%, 65.54%, and 97.47% after one, three, and five days, respectively. Residual levels became undetectable on the 7th day after application until harvest. Additionally, flonicamid chemigation initially showed no residues in green onion samples; however, one day later, the residues increased to 3.83 mg/kg. Three days after treatment, the residue level decreased by 36.03% to 2.45 mg/kg, and by day seven, the residues continued to decline, reaching 0.06 mg/kg, representing a 98.43% reduction.

Onion bulb samples collected 35 and 45 days after insecticide application showed no detectable flonicamid residues. Based on the European Maximum Residue Limit (MRL) of 0.03 mg/kg, the pre-harvest intervals for flonicamid were 5 days for spraying and 10 days for chemigation, with half-lives of 2.28 days and 4.16 days, respectively.

Dissipation of flometoquin

Table 5 shows that the residue of flometoquin in green onions two hours after spraying was 1.62 mg/kg with an RSD of ±4.85%. One day after treatment, residues decreased to 1.21 mg/kg, representing a 25.30% depletion. After three days, the degradation increased to 49.38%, and after five and seven days, degradation continued, reaching 74.07% and 82.09%, with residue levels ranging from 0.42 to 0.29 mg/kg. No flometoquin residues were detected ten days after treatment until harvest. Additionally, onion bulb samples collected 35 and 45 days after treatment were free of flometoquin residues. The pre-harvest interval for onions sprayed with flometoquin was 10 days, with a half-life of 3.03 days.

Table-4. Flonicamid residues, depletion, and half-life in/on green onion and onion bulb following chemigation or spraying.

Days after application	Residues (mg/kg) Chemigation	±RSD %	% Depletion	Residues (mg/kg) Spraying	±RSD %	% Depletion
0	ND	---	---	1.19	3.52	0.00
1	3.83	4.56	0.00	1.02	1.69	14.28
3	2.45	3.68	36.03	0.41	2.74	65.54
5	1.48	9.78	61.35	0.03	6.88	97.47
7	0.06	12.28	98.43	ND	---	---
10	ND	---	---	ND	---	---
15	ND	---	---	ND	---	---
21	ND	---	---	ND	---	---
35	ND	---	---	ND	---	---
45	ND	---	---	ND	---	---
Half-life time (days)	4.16			2.28		
MRL **(EU, 2024)**			0.03			
PHI (days)	10			5		

Table-5. Flometoquin residues, depletion, and half-life in/on green onion and onion bulb following chemigation or spraying.

Days after application	Residues (mg/kg) Chemigation	±RSD%	% Depletion	Residues (mg/kg) Spraying	±RSD%	% Depletion
0	ND	---	---	1.62	4.85	0.00
1	ND	---	---	1.21	5.22	25.30
3	ND	---	---	0.82	6.71	49.38
5	ND	---	---	0.42	3.24	74.07
7	ND	---	---	0.29	9.11	82.09
10	ND	---	---	ND	---	---
15	ND	---	---	ND	---	---
21	ND	---	---	ND	---	---
35	ND	---	---	ND	---	---
45	ND	---	---	ND	---	---
Half-life time (days)	---			3.03		
MRL **(Japan 2017)**				0.05		
PHI (days)	---			10		

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Dissipation of dinotefuran

Table 6 shows the dinotefuran residues in green onion and bulbs after insecticide spraying. The initial residue level, measured two hours post-treatment, was 6.66 mg/kg. One day later, residues decreased to 3.86 mg/kg, reflecting a 42.04% depletion. After three days, the residue level was 3.67 mg/kg. Dinotefuran residues decreased rapidly between five and fifteen days after treatment, with depletion ranging from 64.56% to 98.49%. By 21 days post-treatment, residues were below the detection limit. In contrast, no residues were detected two hours after the dinotefuran chemigation. However, due to its rapid absorption as a super systemic pesticide, residues increased to 6.46 mg/kg one day after treatment. Afterward, residue levels decreased to 2.01, 0.67, 0.21, and 0.05 mg/kg after 3, 5, 7, and 10 days, with RSD values ranging from ±3.67% to 17.11%. Thus, no dinotefuran residues were detected in onion bulb samples collected 35 and 45 days after application. On the other hand, the pre-harvest intervals for dinotefuran in green onions were 15 days for spraying and 10 days for chemigation. The half-lives for both treatments were 3.34 days and 2.17 days, respectively.

Risk assessment of the tested insecticides in green onion

To assess the risk associated with chronic dietary exposure to onion samples with pesticide residues exceeding the MRLs, the percentage of the acceptable daily intake (ADI%) for each pesticide was used. The assessment of chronic risks from pesticide residues in green onions, which exceeded the allowable MRLs, is shown in Tables (7-9). The percentage of the ADI was greater than 100% in all onion samples obtained after flonicamid spraying or chemigation with residues exceeding MRLs, except for those collected three and five days after spraying, which had ADI% values of 51.2% and 3.7%, respectively. Furthermore, all samples collected 0, 1, 3, 5, and 7 days after flometoquin treatment exhibited elevated ADI% values. For dinotefuran chemigation, green onion samples showed high ADI% values after one and three days, but the ADI% fell below 100% on days five, seven, and ten. In contrast, samples sprayed with dinotefuran showed ADI% values greater than 100%, whereas ADI% dropped below 100% after seven, ten, and fifteen days after chemigation.

Table-6. Dinotefuran residues, depletion, and half-life in/on green onion and onion bulb following chemigation or spraying.

Days after application	**Residues (mg/kg) Chemigation**	**±RSD%**	**% Depletion**	**Residues (mg/kg) Spraying**	**±RSD%**	**% Depletion**
0	ND	---	---	6.66	4.37	0.00
1	6.46	3.67	0.00	3.86	6.93	42.04
3	2.01	6.74	68.88	3.67	4.59	44.89
5	0.67	15.21	89.62	2.36	7.29	64.56
7	0.21	17.11	96.74	1.96	3.96	70.57
10	0.05	7.44	99.22	1.36	10.51	79.57
15	ND	---	---	0.10	3.75	98.49
21	ND	---	---	ND	---	
35	ND	---	---	ND	---	
45	ND	---	---	ND	---	
Half-life time (days)	2.17			3.34		
MRL **(Codex 2013)**			0.1			
PHI (days)	10			15		

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Table-7. Residues, national estimating daily intake (NEDI), and acceptable daily intake percentage (ADI%) for flonicamid in/on onion following chemigation or spraying.

Days after treatment	Residues mg/kg (Chemigation)	NEDI	ADI%	Residues mg/kg (Spraying)	NEDI	ADI%
0	ND	---	---	1.19	0.104	148.5
1	3.83	0.334	477.8	1.02	0.089	127.3
3	2.45	0.214	305.7	0.41	0.036	51.2
5	1.48	0.129	184.6	0.03	0.003	3.7
7	0.06	0.005	7.5	---	---	---

Table-8. Residues, national estimating daily intake (NEDI), and acceptable daily intake percentage (AD%) for flometoquin in/on onion following chemigation or spraying.

Days after treatment	Residues mg/kg (Chemigation)	NEDI	ADI%	Residues mg/kg (Spraying)	NEDI	ADI%
0	---	---	---	1.62	0.141	1768.5
1	---	---	---	1.21	0.106	1320.9
3	---	---	---	0.82	0.072	895.2
5	---	---	---	0.42	0.037	458.5
7	---	---	---	0.29	0.025	316.6

Table-9. Residues, national estimating daily intake (NEDI), and acceptable daily intake percentage (ADI%) for dinotefuran in/on onion following chemigation or spraying.

Days after treatment	Residues mg/kg (Chemigation)	NEDI	ADI%	Residues mg/kg (Spraying)	NEDI	ADI%
0	ND	---	---	6.66	0.582	290.8
1	6.46	0.564	806.0	3.86	0.337	168.6
3	2.01	0.176	250.8	3.67	0.321	160.3
5	0.67	0.059	83.6	2.36	0.206	103.1
7	0.21	0.018	26.2	1.96	0.171	85.6
10	0.05	0.004	6.2	1.36	0.119	59.4
15	---	---	---	0.10	0.009	4.4

Discussion

Despite its effectiveness, insecticide foliar treatment has disadvantages, such as public health problems, environmental hazards, and pesticide drift in areas close to urban (Sujithra et al., 2020). On the other hand, drip chemigation is considered one of the effective and safe techniques for pest control. This technique allows the pesticide to bind to the soil, leach into groundwater, or be absorbed by plant roots. Additionally, drip chemigation is a practical and cost-effective alternative to traditional foliar pesticide sprays for controlling specific vegetable pests (Sujithra et al., 2020).

An ongoing effort in onion production focuses on controlling insect pests, including *T. tabaci* (Ashghar et al., 2018; Azazy et al., 2018). Therefore, this study investigated the field efficacy of foliar application and drip chemigation of dinotefuran, flonicamid, and flometoquin against onion thrips. Our results showed that the foliar application of flometoquin could effectively control thrips over two consecutive seasons, which concurs with (Kobayashi et al., 2023), who reported that flometoquin had a faster action against thrips compared to spinetoram and cyantraniliprole, leading to a more effective reduction in virus transmission. Additionally, (Kobayashi et al., 2023) suggested that the properties of flometoquin could significantly aid both domestic and global farmers in managing thrip resistance.

Drip chemigation of flonicamid effectively controlled onion thrips for 45 days compared to 20 days with foliar application. These results are consistent with (Jiang et al., 2020), who reported that flonicamid provided effective control through drip chemigation, with a strong residual effect lasting 40 days against cotton aphids, compared to 20 days with spray application. Thus, our study further supports the effectiveness of chemigation over foliar application, and this is consistent with several studies that reported that drip application of systemic insecticides can be an effective method for controlling crop pests (Schuster et al., 2009; Kuhar et al., 2010; He et al., 2018; Jiang et al., 2020). In some cases, a single drip application of insecticides per season provided equivalent or even better control of specific insect pests compared to foliar application (Ghidiu et al., 2009). However, there was concern that the soil might adsorb the insecticide, potentially reducing its effectiveness (Gennari and Gessa, 1999).

Foliar spraying of neonicotinoids such as imidacloprid, thiamethoxam, clothianidin, and dinotefuran is a common method for controlling sucking and piercing insects. However, the increasing negative impact on important pollinators like bees has led to bans on pesticide application in open fields. In our study, dinotefuran has shown effective control of onion thrips through drip irrigation and foliar application. These results are consistent with (Van Timmeren et al., 2011), who reported that soil application provides superior long-term protection compared to foliar treatments, as declining residues on foliar-treated plants lead to reduced effectiveness within 2-3 weeks. Additionally, dinotefuran's rapid uptake (Morse et al., 2007) resulted in good control when applied via drip irrigation. Flometoquin is less water-soluble than flonicamid and dinotefuran, which reduces leaf contamination when similar injection rates are used.

Generally, the tested compounds' insecticidal mechanisms differ from those of conventional insecticides and exhibit low toxicity to beneficial insects (Tan et al., 2023; Sakthiselvi et al., 2024). These compounds pose no risk to vertebrates, as well as humans, due to their significantly lower attraction for the target receptor in vertebrates, compared with insects (Sass and Raichel, 2024). However, dinotefuran insecticide can affect honeybees (Chen et al., 2021) and soil microorganisms (Yin et al., 2023).

On the other hand, the present results indicated that systemic insecticides significantly affected the vegetative growth of onion plants. Dinotefuran and flonicamid induced onion plant height and the number of leaves. Neonicotinoids, which have systemic effects, potentially benefit plant growth and stress responses (Afifi et al., 2015). Among the treatments, the foliar application of flometoquin demonstrated the highest efficacy. It resulted in the greatest average bulb weight and total yield per square meter, followed by flonicamid chemigation, flonicamid foliar application, dinotefuran chemigation, dinotefuran foliar application, and finally, flometoquin chemigation, which showed the lowest efficacy.

Soil application of systemic insecticides provides long-term control of insect pests (Van Timmeren et al., 2012). In our study, flonicamid and dinotefuran accumulated in plant tissues and degraded at rates ranging from moderate to rapid, exhibiting a gradual reduction in residual levels. These findings align with (Zhang et al., 2022), who reported that the residue and dissipation kinetics of flonicamid in peach, cucumber, cabbage, and cotton exhibited a high rate of degradation, with RSD values ranging from 0.41% to 5.95% and half-lives ranging from 2.28 to 9.74 days.

Additionally, the terminal residue of flonicamid was below the MRL, with a risk quotient (RQ) of 4.4%, well below 100%. A similar trend was observed in the residual dissipation of flonicamid, dinotefuran, and their metabolites in peach matrices (Xu et al., 2021). These findings showed average recoveries for these analytes ranging from 94% to 108%, with a relative standard deviation ranging from 1.0% to 8.8%. The dissipation behaviors of flonicamid and dinotefuran were described using a first-order dynamic kinetics model. The half-lives for the two compounds were 6.9–12.4 days and 8.1–15.1 days, respectively. Thus, a 21-day preharvest interval (PHI) was recommended, and the RQ values for the two compounds were 16.6% and 20.7%, respectively, significantly below 100%.

Moreover, dinotefuran was soil-applied at plant back intervals of 30 and 60 days (PBI-30 and PBI-60), and residues of dinotefuran and its metabolites were estimated. The half-lives and bio-concentration factors were calculated (Ham et al., 2022). The uptake of dinotefuran by lettuce and celery ranged between 23.8% and 28% and between 51.73% and 53.06%, respectively. Respective half-lives (days) of dinotefuran applied on PBI-30 and PBI-60 were 1.33–1.54 and 0.91–2.16 in lettuce soil and 0.9–1.47 and 0.79–1.65 in celery soil. Residues were below Korean MRLs in PBI-60 and most PBI-30 samples. The calculated risk assessment parameters indicated that negligible risk could be expected (Ham et al., 2022). Furthermore, some researchers studied the dissipation rates of conventional insecticides such as profenofos and metalaxyl in green onion. After 14 days of spraying, the dissipation of profenofos was faster than metalaxyl, with half-lives of 0.91 and 3.92 days, respectively, while the maximum residue limits (MRLs) of profenofos and metalaxyl were 0.5 and 2.0 mg/kg (Sallam, 2008). Thus, dissipation kinetics are crucial because the degradation products could show toxicological effects and pose greater environmental risks (Kandil et al., 2023; Moustafa et al., 2022).

Conclusions

In conclusion, our study demonstrated that drip chemigation with dinotefuran and flonicamid offers a promising and economically viable approach for the sustainable management of onion thrips. This method reduces application frequency and minimizes applicator exposure without adversely affecting onion plants. Additionally, the MRL must not be exceeded in pesticide residues detected in foods to maintain human health safety, avoid cumulative effects on human health and environment, save producers and exporters from loss as result from rejecting at borders and avoid loss of consumer trust.

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Contribution of Authors

Moustafa MAM: Conceptualization, methodology, writing original draft, review, editing, visualization, project supervision and administration.
Helmy RMA & Ibrahim ES: Helped with methodology, original draft preparation, review, editing, visualization and project supervision.
Alfuhaid NA: Contributed to the software analysis, validation, formal analysis, project supervision and resources management.
All authors read and approved the final version of the manuscript.

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