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Evaluation of The Effect of Metalaxyl-M and Chlorothalonil Against Downy Mildew in Cucumber and Investigation of Their Residues

Metalaxyl-M ve Chlorothalonil'in Hıyarda Tüylü Küf Hastalığına Karşı Etkisinin Değerlendirilmesi ve Kalıntılarının Araştırılması

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ABSTRACT: Cucumber (*Cucumis sativus* L.), one of the 30 *Cucumis* species found worldwide, is the most economically significant. *Pseudoperonospora cubensis*, a causative agent of downy mildew, affects cucumbers and other cucurbits. Using a combination of the QuEChERS technique and HPLC, the residue levels and rate of degradation of the commercial fungicide, contained two active components (metalaxyl-M and chlorothalonil), in the cucumber were determined. Additionally, the fungicide's effectiveness was assessed. The experiment was conducted in a greenhouse with a randomized block pattern in the eastern Iraqi city of Ramadi, Anbar Governorate. Cucumbers grown in greenhouses were found to have high amounts of metalaxyl-M and chlorothalonil residues. The fungicide required about 14 days to completely dissipate from the cucumber fruits. The recoveries of chlorothalonil and metalaxyl-M were 90.3% and 86.7%, respectively. The half-lives of metalaxyl-M and chlorothalonil were determined as 0.90 and 0.85, respectively.

Keywords: Cucumber, Metalaxyl-M, Chlorothalonil, HPLC, downy mildew

ÖZ: Hıyar (*Cucumis sativus* L.), dünya çapında bulunan 30 hıyar türünden biri olup ekonomik açıdan en önemli olanıdır. *Pseudoperonospora cubensis*, salatalık ve diğer kabakgilleri etkileyen en yıkıcı yaprak hastalıklarından biri olan tüylü küfe neden olan mantardır. QuEChERS tekniği ve HPLC'nin bir kombinasyonu kullanılarak, iki aktif bileşen (metalaxyl-M ve chlorothalonil) içeren ticari fungisitlerin salatalıktaki kalıntı seviyeleri ve bozunma oranları tespit edilmiştir. Ayrıca, fungisitlerin etkinliği de değerlendirilmiştir. Deney, Irak'ın doğusundaki Anbar vilayetinin Ramadi kentinde bulunan tesadüfi blok desenli bir serada, salatalık mahsulü üzerinde yürütülmüştür. Seralarda yetiştirilen salatalıklarda yüksek miktarda metalaxyl-M ve chlorothalonil kalıntıları bulunmuştur. Fungisitin salatalık meyvelerinden tamamen kaybolması için yaklaşık 14 gün gerekmiştir. Klorotalonil ve metalaksil-M'nin geri kazanımı sırasıyla %90,3 ve %86,7 olmuştur. Metalaxyl-M ve klorothalonil'in yarı ömürleri sırasıyla 0.90 ve 0.85'tir.

Anahtar Kelimeler: Hıyar, Metalaxyl-M, Chlorothalonil, HPLC, tüylü küf

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1. INTRODUCTION

The growing global demand for food due to the expanding human population is being challenged by various factors, including plant diseases that are impacting agricultural production. As a response, the use of pesticides in agriculture has been instrumental in reducing diseases and enhancing productivity. While pesticides play a crucial role in disease control and financial returns for farmers, their extensive use raises concerns about environmental pollution in soil, water, air, and food, as well as potential residues in plants (Ghanbari et al., 2024). Global organizations such as the Food and Agriculture Organization (FAO), the United States Environmental Protection Agency (USEPA), and the World Health Organization (WHO) caution against the risks associated with pesticide residues in humans, citing increased incidences of cancer and asthma, as well as adverse impacts on the reproductive system and embryo development (WHO, 2017). Extensive research on Maximum Residue Limits (MRL), pesticide residues, and determining post-harvest and pre-harvest intervals in crops is carried out by global research centres, universities, and research institutes in industrialized nations (Damalas and Eleftherohorinos, 2011). In the context of global food trade, understanding the minimum and maximum limits of pesticide residues, conducting analysis, and monitoring residues is essential. Industrialized nations have implemented strict regulations concerning these values to safeguard food safety and quality throughout the supply chain. The MRL values of different fruit and vegetable crops are set by national legislation. In making this decision, the World Food Organization and the World Health Organization are involved. However, the international borders established by the Codex Alimentarius Commission are used, as there are no local borders in Iraq. Since many farmers disregard advised dosages and post-application intervals in an attempt to boost crop yields, inspecting pesticide residues is crucial in all developing nations, including Iraq (Damalas and Eleftherohorinos, 2011).

The most valuable member of the Cucurbitaceae family in terms of commerce is the cucumber (*Cucumis sativus* L.). Due to its high-water content, this vegetable is widely used. Because of their limited shelf life, cucumbers are frequently used in salads or preserved in other ways, including pickling or marinating (Savory et al., 2011; Zieliński et al., 2017). While cucumbers are cultivated in Iraq, they are also imported from other countries. One of the most significant diseases affecting cucumbers and other cucurbits is mildew caused by *Pseudoperonospora cubensis.*

Numerous research studies have shown that a significant portion of pesticide active ingredients is concentrated in the peel of fruits and vegetables, including cucumbers. Therefore, techniques employed to remove the peel or outer layer of agricultural produce can substantially reduce the presence of absorbed or adhered pesticides on the fruits (Awasthi et al., 1993). Given that home remedies are perceived as the most practical and cost-effective solutions in underdeveloped countries, they are primarily emphasized for pesticide removal. Reducing pesticide residue at home can be achieved through conventional methods such as washing or peeling crops before consumption. Hence, it is essential to reduce the levels of toxic substances. Methods for achieving this include washing vegetables with water, utilizing kitchen chemicals such as sodium permanganate, employing baking soda (sodium bicarbonate), and using vinegar (Krol et al., 2000). It is important to highlight that there is limited research and documentation on the efficacy of these methods in effectively reducing the levels of harmful chemicals present in fruits and vegetables (Omer et al., 2019).

The study aims to investigate the efficacy of metalaxyl-M and chlorothalonil as active ingredients in controlling mildew disease in greenhouse-grown cucumbers, while also determining their half-lives and residual levels.

2. MATERIAL and METHODS

2.1. Chemicals and Reagents

The fungicide Folio Gold® 537.5 SC, comprising two distinct groups (Metalaxyl-M 37.5 gm/L + Chlorothalonil 500 gm/L), was locally sourced and applied at the recommended dose in a greenhouse experiment for this study.

2.2. Greenhouse Trials

In a 5 by 18-meter greenhouse situated in the eastern Iraqi city of Ramadi within the Anbar Governorate, an experiment was carried out on cucumber crops. The soil in the greenhouse was analyzed at the Soil Research Center's labs, revealing a sandy texture, an electrical conductivity salinity of 6.0 dSm^{-1}, and a pH of 7.6. The experimental site was arranged with four rows of cucumber seedlings, spaced 35 cm apart, after sowing the seeds on cork plates on September 25, 2021. The seedlings were subjected to pesticide treatment. Each of the three replicates was divided into four treatments: three for fungicide application and one for comparison (without pesticides). In the third treatment (commercial pesticide), the recommended dose was applied twice, with the required amount of 2.5 mL/ L, administered two days after the initial treatment. A 5-liter handheld sprayer was utilized to apply the pesticide Folio Gold® 537.5 to cucumber plants to prevent interference or contamination. Samples were collected at specific intervals: 2 hours' post-application, and at 1, 7, 10, and 14 days, with 1 kg per treatment as per Soliman (2021). Control samples were collected immediately after obtaining cucumbers during each sampling phase of the experiment. Table 1 details the commercial formulations, dosages, and Maximum Residue Limits (MRL) of the pesticide. Additionally, untreated cucumber fruits were stored for comparison. To prevent degradation, all samples were placed in vacuum-sealed polyethylene bags and stored at -20°C (Đorđević and

Đurović-Pejčev, 2016).

Table 1. Fungicide formulation, rate, exposure limit, and MRL

Common name	Commercial name	Rate mL/L	Exposure limit	*MRL (mg/kg)
Metalaxyl-M	Folio Gold® 537.5 SC	2.5 mL/ L	10 mg/m^3	0.50
Chlorothalonil			0.1 mg/m^3	3.00

**MRL = Maximum residual limits at Codex committee on pesticide residues*

2.3. Extraction, Purification and Analysis Processes

A sample weighing approximately 1000 g of cucumber fruits or 100 g of cucumber leaves was frozen, crushed to homogeneity with a plastic mallet inside a bag, and mixed thoroughly by rotating the bag. Subsequently, 10 g of the sample was combined with 10 mL of acetonitrile (ACN) and processed using an electric mixer or homogenizer. For soil samples, the bag was shaken to achieve a uniform mixture without a mixer, followed by the addition of 10 milliliters of acetonitrile. The remaining steps for leaves and fruits involved mixing the sample for a minute at 500 cycles per minute. The QuEChERS method, as described by (Anastassiades et al., 2003) was then employed for further analysis.

2.4. HPLC Procedure and Method Validation

The analysis utilized the SHIMADZU/LC-20AD HPLC system equipped with a UV/vis detector. Standard solutions for metalaxyl-M (CAS No. 70630-17-0) and chlorothalonil (CAS No. 1897-45-6) from Merck® were prepared following the manufacturer's guidelines (Table 2). These solutions were then tested using the HPLC equipment to establish standard curves for metalaxyl-M and chlorothalonil calibration. During the assessment of the analytical method in three replicates, various criteria such as fungicide recoveries, limit of detection (LOD), limit of quantification (LOQ), and repeatability expressed as Relative Standard Deviation (RSD) were considered to validate the method. Recovery calculations were conducted on untreated cucumber fruits for the three fungicide treatments (0.01, 0.5, and 1.0 mg/kg). The linear range for the analysis was 0.01 to 0.1 µg/mL.

Table 2. Conditions of HPLC apparatus for detecting Metalaxyl-M and Chlorothalonil

Pesticides	Detection wavelength(nm)	Flow rate	Mobile phase	Volume
Metalaxyl-M	225	0.8 mL/min	Acetonitrile/methanol/water	40:20:40
Chlorothalonil	230	1.0 mL/min	acetonitrile/water	70:30

2.5. Recovery Efficiency

To assess the recovery efficiency, two concentrations were employed, one derived from standard solutions. Recovery efficiency was validated by comparing the control solution containing the standard solution with the other two solutions from contaminated cucumbers treated with the same standard solution. Following the extraction and purification processes, a comparison was conducted to ascertain the percentage recovery efficiency.

2.6. Measuring the Efficacy of Metalaxyl-M and Chlorothalonil Against Downy Mildew

Before evaluating the severity of the infection, the presence of the downy mildew pathogen in cucumbers was identified. Subsequently, 20 leaves were marked in three replicates, each comprising three treatments and one control. Over a period of 45 days, readings were taken every two weeks (totalling three readings) to determine the infection severity using a five-degree pathological index as outlined in Table 3.

Table 3. Disease severity in areas occupied by the causative fungus on the leaf

Disease severity	Areas occupied by the fungus that causes downy mildew on the leaf
zero	intact paper
one	(1–25) percent of the leaf area is infected with the causative fungus
two	(25–50) percent of the leaf area is infected with the causative fungus
three	(50–75) percent of the leaf area is infected with the causative fungus
four	(75–100) percent of the leaf area is infected with the causative fungus

2.7. Statistical Analysis

In the laboratory research, a Complete Randomized Design (CRD) was employed, whereas a Randomized Complete Block Design (RCBD) was utilized for the greenhouse experiments. Significant differences between the means in the RCBD design were compared at a 0.05 probability level to analyze the outcomes. According to Moye et al. (1987), half-life times (t1/2) of the recovery of metalaxyl-M and chlorothalonil residues were computed theoretically. Using the least significant difference test (USA, Chicago SPSS v. 20), the (L.S.D.) was applied. According to Moye et al. (1987), figures for the half-lives of metalaxyl-M and chlorothalonil residues "(t1/2)" have been calculated. The fungicide residue concentration at time t is represented by the first-order kinetics equation "(Ct=C0e-kt)", where C0 is the initial deposits following application and k is the constant rate of fungicide disappearance per day. The half-life of the fungicide under investigation "(t1/2=ln 2/k)" can be computed using this equation (Soliman, 2021).

3. RESULTS and DISCUSSION

3.1. Method Validation of Metalaxyl-M and Chlorothalonil

The metalaxyl-M data exhibited excellent linearity. The Maximum Residue Limits (MRLs) for metalaxyl were notably lower than the quantification limits, which were established at 0.01 mg/kg for metalaxyl-M. The method was deemed feasible based on the EU method validation guidelines, with a Relative Standard Deviation (RSD) of 20 percent (Pihlström et al., 2021). The mean recoveries of metalaxyl-M were 86.66%. During the development of the method, it fully complied with the acceptable recovery range, which ranged from 70% to 120%. This indicates that the QuEChERS sample preparation method, when coupled with HPLC analysis, is appropriate for quantifying the residues of the examined fungicides in cucumber fruits. (Table 4).

Table 4. Recovery and SD values for metalaxyl-M in cucumber fruits

Metalaxyl-M			
Spike level mg/kg	**Recovery±SD**	**Mean±SD**	**RSD%**
0.1 (n=3)	84.0 ±4.87	86.66±4.84	4.50
0.5 (n=3)	89.0 ±8.76		8.45
0.01 (n=3)	87.0 ±1.03		0.90
LSD 5%		2.19	

n= replicates of test
LSD: Least significant difference

The results for chlorothalonil indicated excellent linearity, with maximum permissible levels (MRLs) lower than the 0.01 mg/kg limits of quantification for metalaxyl-M. The RSD met the EU method validation requirements, achieving 20 percent. The mean recoveries of chlorothalonil were 90.33%. During the development of the method, it fully complied with the acceptable recovery range, which ranged from 70% to 120%. These findings demonstrate the suitability of the QuEChERS sample preparation method for quantifying the residues of the studied fungicides in cucumber fruits when paired with HPLC analysis (Table 5).

Table 5. Recovery and SD values of chlorothalonil in cucumber fruits

Chlorothalonil			
Spike level mg/kg	**Recovery±SD**	**Mean±SD**	**RSD%**
0.1 (n=3)	87.0 ±6.25	90.33±5.46	6.0
0.5 (n=3)	91.0 ±6.43		6.0
0.01 (n=3)	93.0 ±9.84		9.50
LSD 5%		2.69	

n= replicates of test
LSD: Least significant difference
** Values holding the identical letters are considered nonsignificant, p>0.05*

3.2. Dissipation in Fruits of Cucumbers in Field Conditions

3.2.1. Metalaxyl-M dissipation in cucumber fruits under field conditions

The study assessed the levels of metalaxyl-M residues and their dissipation rates following three treatments on cucumber fruits at recommended rates for greenhouse conditions. Initial residues were measured at 3.32 mg/kg two hours' post-application. The results demonstrated a significant decrease in the concentrations of both fungicides over time post-treatment. Particularly, metalaxyl-M dissipated rapidly after application. The detailed results are presented in Table 6 and Figure 1.

The residue levels in cucumber fruits notably decreased to 1.63 mg/kg within the first twenty-four hours after the application of metalaxyl-M. Subsequently, the concentration decreased significantly to 0.32 and 0.05 after 7- and 10-days' post-treatment, respectively. Both fungicide residues were undetectable after 14 days of treatment. The investigation indicated evidence of first-order kinetics for fungicide residues in cucumber fruits. The Maximum Residue Limit (MRL) was calculated based on Authority (2015).

Table 6. Determination of metalaxyl-M in cucumber fruits at different time intervals

	Metalaxyl-M	
Day after treatment	**Metalaxyl-M Residues (mg kg^{-1})**	**Dissipation percentage**
No treatment	0.00	0.00
Zero (after 2 hours)	3.32 ± 1.34	0.00
1	1.63 ± 0.28	49.57
7	0.32 ± 0.18	90.87
10	0.05 ± 0.03	97.89
14	0	0
t1/2 day	0.90	

3.2.2. Chlorothalonyl dissipation in cucumber fruits under field conditions

The investigation assessed the levels of chlorothalonil residues and their dissipation rates following three treatments on cucumber fruits at recommended rates for greenhouse conditions. Initial residues were measured at 4.42 mg/kg two hours' post-application. The results indicated a significant decrease in the concentrations of both fungicides at various time points post-treatment. Detailed findings displayed in Table 7 and Figure 1.

Table 7. Determination of chlorothalonil in cucumber fruits at different times

	Chlorothalonil	
Day after treatment	**Chlorothalonil Residues (mg kg^{-1})**	**Dissipation percentage**
No treatment	0.00	0.00
Zero	4.42 ± 1.73	0.00
3	1.09 ± 0.49	76.43
7	0.61 ± 0.27	87.65
10	0.03 ± 0.05	99.16
14	0	0
t1/2 day	0.85	

Chlorothalonil dissipates rapidly after application, with concentrations decreasing to 1.09, 0.61, and 0.03 mg/kg three, seven- and ten-days' post-treatment, respectively. Both fungicide residues became undetectable 14 days after treatment. The dissipation pattern observed in tomato fruits mirrored that of chlorothalonil. (Al-Rahman et al., 2012). The fungicide residue investigation on cucumber fruit revealed evidence of first-order kinetics. The Maximum Residue Limit (MRL) was calculated based on the findings from Authority (2015).

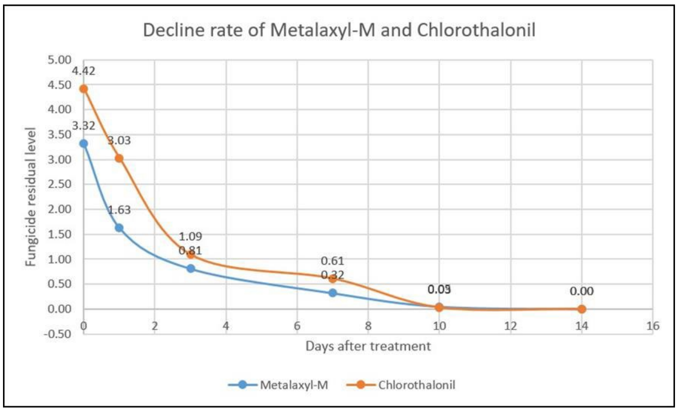

Figure 1. Metalaxyl-M and chlorothalonil decline rates in this study

The half-lives of chlorothalonil and metalaxyl-M were determined to be 0.90 and 0.85 days, respectively. Previous studies by Al-Rahman et al. (2012) and Soliman (2021) indicated that the pre-harvest intervals (PHI) for metalaxyl-M and chlorothalonil were seven and three days, respectively. Additionally, Gambacorta et al. (2005) observed varying dissipation behaviours for chlorothalonil in different vegetables, such as tomato fruits and cabbages (Zhang et al., 2007). Metalaxyl-M is recognized as a broad-spectrum fungicide with registered use on a variety of crops across different regions worldwide (Urech et al., 1977). In addition to its positive impact on plant growth and agricultural productivity, metalaxyl-M was observed to exhibit moderate stability under the standard environmental conditions that were studied (Kamrin, 1997).

The observed metalaxyl-M residue half-life values and dissipation rates in cucumber align with findings reported by Talebi (2002). Variations in the dissipation rates of the two fungicides could be attributed to differences in their physiochemical and chemical structures, as well as factors such as photolysis, biotic and abiotic activities in field conditions, which influence their persistence in environments with diverse climate characteristics. The dissipation variations observed in fungicides can be influenced by a combination of biotic and abiotic processes, including photolysis. Egypt, a significant producer of cucumbers, cultivates some crop rich in antioxidants and nutrients. The primary objective of integrated pest management (IPM) strategies is to promote sustainable agricultural practices by minimizing pesticide use to mitigate the environmental impact of highly hazardous pesticides. Monitoring pesticide residues is a key aspect of integrated pest management (IPM) as it aids in determining proper dosages and establishing Pre-Harvest Interval (PHI) values. Test outcomes must adhere to standard limits to confirm the behaviour of residual metalaxyl-M and chlorothalonil. The Limits of Quantifiable Exposure (LOQ) for both insecticides were below the Maximum Residue Levels (MRLs) established by the EU and the Codex Committee. The methods utilized demonstrated effective separation of the examined fungicides, with the QuEChERS methodology yielding excellent recoveries. Previous tests indicate that the levels of metalaxyl and chlorothalonil residues deemed acceptable for cucumber fruits in Egypt. Considering the results, reducing treatment dosages and implementing a safe pre-harvest interval of seven days before selling cucumber fruits as fresh produce aligns with recommendations (Gambacorta et al., 2005).

Dipping fruits and vegetables, like cucumbers, in a sodium chloride (table salt) solution can be a cost-effective and time-saving way to reduce pesticide residues. When Chinese cauliflower is soaked in a 1% brine solution for five minutes, most of the chlorothalonil can be removed from the vegetable, effectively reducing pesticide residues. Vemuri et al. (2014) demonstrated the efficacy of this method in removing suspended pollutants.

3.2.3. Efficacy of Metalaxyl-M and Chlorothalonil against Downy Mildew in cucumber

The use of metalaxyl-M and chlorothalonil demonstrated effectiveness in mitigating the disease affecting cucumber plants, as indicated by the results. In untreated cucumber plants, the infection severity on leaves increased over time, from 1.32 before treatment to 4.9 post-infection (Table 8).

Table 8. Efficacy of Folio Gold® 537.5 SC against downy mildew in cucumber

Disease severity assessment dates	Disease severity range (0-5)			
	DS1	**DS2**	**DS3**	**DS4**
One day before treating cucumber with pesticides	1.32	1.32	1.99	1.34
After two weeks of treatment	3.32	1.32	1.99	1.34
After four weeks of treatment	4.32	1.32	1.99	1.34
After six weeks of treatment	4.99	1.32	1.99	1.34
LSD 5%	1.78*	NS	NS	NS

DS: Disease severity; DS1: Disease severity, treatment without the use of fungicide; DS2: Disease severity, treatment with the recommended concentration (1.5 g L^{-1} water); DS3: Disease severity, treatment with a double concentration; DS4: Disease severity, treatment with the recommended concentration (1.5 g L^{-1} water), and respray after two days.

Conversely, the presence of metalaxyl-M and chlorothalonil on leaf surfaces, along with their antifungal properties, suppressed the development of new infection sites, contrasting with the untreated cucumber plants. Metalaxyl-M and chlorothalonil act by inhibiting the establishment of new infection sites for the downy mildew-causing fungus, either by preventing the germination of fallen conidia or by disrupting the germination tubes. This capability to suppress the germination of deposited conidia underscores the fungicides' efficacy in thwarting the formation of new pathogen populations. With a protective duration of four weeks, these fungicides serve as both preventive and curative agents. Application one week prior to the expected arrival of conidia spores is recommended for optimal efficacy. The application of pesticides prevented the development of new infections on cucumber leaves, as evidenced by stable infection severity values over five to six weeks compared to untreated leaves. Treating plants according to recommended protocols yielded positive outcomes, eliminating the necessity for additional treatments or increased pesticide concentrations within two days.

3.3. Immersion in Chemical Solutions

The study demonstrated that sodium bicarbonate removed 98.5% of the insecticide when the concentration reached 0.5 mg L^{-1}. Similarly, soaking cucumber fruits in a fungicide concentration of 1 g L^{-1} resulted in 98.5% removal of potassium permanganate. Both solutions efficiently achieved a concentration of 0.5 mg L^{-1} in terms of pesticide removal from the fruit surfaces. The application of acetic acid (vinegar) on cucumber fruits resulted in the removal of 96.5% of the fungicide after a ten-minute submersion. This method effectively reduced the fungicide concentration from 34 mg L^{-1} to 0.5 mg L^{-1}, similar to the efficacy demonstrated by sodium bicarbonate and potassium permanganate solutions. However, treating cucumber fruits with vinegar and salt at concentrations of 50 g/L and 100 g/L did not effectively eliminate the pesticide residue, with removal percentages ranging from

75% to 80% as the concentration reached 8.50 and 6.75 mg L^{-1}, respectively. These findings align with similar outcomes observed in an Iraqi study on greenhouse-grown cucumbers (Al-Oubaidie et al., 2018).

The application of integrated pest management (IPM) strategies plays a crucial role in reducing pesticide usage and mitigating the environmental impact of harmful chemicals in agriculture. Monitoring pesticide residues, such as metalaxyl-M and chlorothalonil, is essential for predicting appropriate dosages and ensuring compliance with safety standards. Efficient methods like the QuEChERS technique have shown promising results in removing pesticide residues from fruits and vegetables, contributing to safer agricultural practices.

Furthermore, the study highlights the effectiveness of fungicides like metalaxyl-M and chlorothalonil in managing diseases such as downy mildew in cucumber plants. These fungicides not only prevent the establishment of new infection sites but also exhibit persistence, protecting plants for extended periods. The successful reduction of infection severity on treated cucumber leaves compared to untreated ones underscores the importance of timely and proper pesticide application.

Moreover, the research explores various methods for pesticide residue removal from cucumber fruits, including sodium chloride, vinegar, and salt solutions. These methods have shown varying degrees of efficacy in eliminating pesticide residues, with acetic acid demonstrating high removal efficiency. Understanding the degradation and persistence of fungicides like Folio Gold® 537.5 SC in cucumber fruits is crucial for determining safe application practices and ensuring minimal environmental impact.

In conclusion, the study emphasizes the importance of implementing sustainable pest management practices, verifying pesticide residues, and evaluating the efficacy of different removal methods to promote food safety and environmental sustainability in agriculture. Additionally, the need for thorough assessment of degradation products before importing fungicides underscores the significance of regulatory measures to safeguard public health and the environment.

4. CONCLUSIONS

The research revealed that it took approximately 14 days for the fungicide Folio Gold® 537.5 SC to completely dissipate from cucumber fruits. The Maximum Residue Limit (MRL) values for Metalaxyl-M and Chlorothalonil were determined to be 0.50 and 3.1, respectively, within acceptable limits. Metalaxyl-M and Chlorothalonil exhibited half-lives of 0.90 and 0.85, respectively, indicating their persistence. The application of Metalaxyl-M and Chlorothalonil successfully mitigated the disease affecting the cucumber plants. For effective control of downy mildew disease in cucumbers, it is advisable to apply Folio Gold® 537.5 SC fungicide to the soil. Prior to the importation of authorized fungicides into Iraq, it is crucial to verify the presence of degradation products to ensure environmental safety.

Author Contribution

Saifuldeen Jasim Mohammed MOHAMMED: (b) Study Design, Methodology, (f) Data Collection, Processing, (I) Critical Review

Gülşen GÜÇLÜ: (c) Literature Review, (h) Writing Text

Danial KAHRİZİ: (c) Literature Review, (h) Writing Text

Tuğba GÜRKÖK TAN: (a) Idea, Concept, (d) Supervision, (g) Analyses

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions against Scientific Research and Publication Ethics" are not carried out.

Conflict of Interest

The authors report there are no competing interests to declare.

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