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Simultaneous Quantification of Dinotefuran, Pyriproxyfen, and Diafenthiuron by Reverse Phase Ultrafast Liquid Chromatography: Application to Food, Agrochemical, and Environment Samples

Rakesh Singh[1], Smriti Sharma[2] and Jayesh Dhalani[1*]

[1]Department of Chemistry, School of Science, RK University, Gujarat, India
[2]Department of Chemistry, Miranda House, University of Delhi, Delhi, India

***Correspondence to:**
Jayesh Dhalani
Department of Chemistry,
School of Science,
RK University,
Gujarat, India.
E-mail: jayesh.dhalani@rku.ac.in

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Abstract

Rapid multi pesticide residue analysis methods are nowadays in demand to authentify food, agrochemical and environment samples. Aim of the study was to develop accurate and rapid method for analysis of dinotefuran, pyriproxyfen, and diafenthiuron by reverse phase ultrafast liquid chromatographic (RP-UFLC). The chromatographic conditions were optimized using a Shim-Pack GIST-HP (2.1 mm × 50 mm, 1.9 μ) column with a mobile phase comprising acetonitrile and water (65:35 v/v). Fine-tuning key parameters such as column's temperature (40 °C), flow (0.6 mL per min) and wavelength (240 nm) enabled superior separation and sensitivity, ensuring minimal retention time and sharp peak resolution despite the complex matrix. Linearity studies demonstrated excellent correlation (R^2 > 0.999) over a wide concentration range, ensuring accurate quantification across varying concentrations. Intra- and inter-day precision values showed percent relative standard deviation (%RSD) well within 2.0%. The accuracy was validated through recovery rates ranging between 99.75% and 100.07% for all three active ingredients. Robustness tests revealed no significant variations in results under minor changes in chromatographic conditions. Furthermore, the method is suitable for residue samples including water, fruits, and vegetables ensuring comprehensive monitoring of presence in various matrices per SANCO guidelines.

Keywords

Reverse phase ultrafast liquid chromatographic, Multi-residue analysis, Dinotefuran, Pyriproxyfen, Diafenthiuron

Introduction

Pesticides play a critical role in ensuring high crop yields and protecting agricultural produce from pests and diseases, making them indispensable in modern farming [1]. However, their widespread use has led to considerable concerns regarding residual contamination in food and the environment, frequently associated with negative health impacts on humans [2]. Traditional analytical techniques, though effective, are often time-consuming and resource-intensive, especially when dealing with multi-pesticide analysis [3]. This study seeks to overcome these challenges by designing and validating a precise and sustainable RP-UFLC technique for concurrently quantifying dinotefuran, pyriproxyfen, and diafenthiuron in intricate agrochemical suspension concentrate formulations, ensuring versatility across different matrices.

Dinotefuran, developed by Mitsui chemicals, is a third-generation neonicotinoid insecticide belonging to the nitroguanidine chemical family.

It is highly effective against sap-feeding pests like aphids and whiteflies, commonly used in crops such as rice, cotton, and vegetables [4, 5]. Pyriproxyfen, developed by Sumitomo chemical, is a pyridine-based insect growth regulator that disrupts insect development by mimicking juvenile hormones. It demonstrates significant efficacy in controlling pests, including whiteflies and aphids, and is widely applied in crops like citrus, cotton, and vegetables [6]. Pyriproxyfen's selectivity and low mammalian toxicity make it a key component in eco-friendly pest management programs. Its long-lasting action supports sustainable agriculture by reducing reliance on traditional insecticides [7]. Diafenthiuron, developed by Syngenta, is a thiourea-based insecticide and acaricide that inhibits mitochondrial respiration, effectively controlling pests like whiteflies, aphids, and mites [8]. It is widely used in crops such as cotton, vegetables, and tea. With its selective action and degradation into less harmful metabolites, diafenthiuron supports eco-friendly pest management. Its long-lasting efficacy makes it a valuable tool for sustainable agriculture [9]. Figure 1 illustrates the molecular structures of dinotefuran, pyriproxyfen, and diafenthiuron. This study focuses on creating an RP-UFLC strategy for jointly analyzing dinotefuran, pyriproxyfen, and diafenthiuron in pesticide formulations. The proposed approach emphasizes efficiency, rapid execution, and eco-friendliness, addressing a key limitation in existing analytical practices [10-13]. Although methods for individual compound analysis are available, the absence of a combined analytical procedure for these three compounds underlines the necessity of this work [14-17].

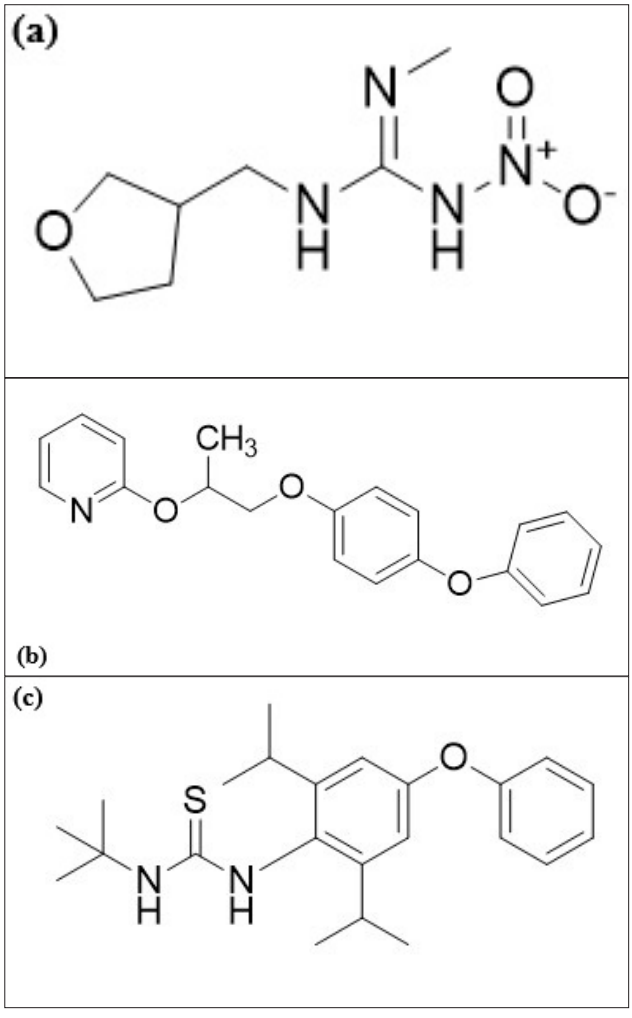


Figure 1: Chemical structures of **(a)** dinotefuran, **(b)** pyriproxyfen, and **(c)** diafenthiuron.

The proposed approach ensures higher reliability, accuracy, and specificity, while also significantly optimizing the time required for analysis, making it highly applicable for the quality assessment of vegetables, fruits and different crops. The method's applicability extends to technical-grade materials and complex sample types such as environmental water and agricultural produce. This broad scope enhances its relevance for both regulatory compliance and residue monitoring across diverse agrochemical applications.

Materials and Methods

Chemicals and laboratory grade-reagents

Acetonitrile of analytical grade and water suitable for high-performance liquid chromatography (HPLC) use were procured from Rankem. Certified reference materials for dinotefuran, pyriproxyfen, and diafenthiuron were sourced from Seedlings India Pvt. Ltd. The formulation item, including dinotefuran (5%) + pyriproxyfen (8%) + diafenthiuron (18%) SC, was also arranged from Seedlings India Pvt. Ltd.

Instrumental and chromatographic condition

The amounts of dinotefuran, pyriproxyfen, along with diafenthiuron throughout the dosage form have been determined utilizing regulated UFLC equipment set to isocratic mode at 240 nm. The mobile phase was made up from water with acetonitrile using a 35:65 (v/v) ratio. The separation using chromatography was done using to Shim-Pack GIST-HP (2.1 mm × 50 mm, 1.9 µ) having an initial two µL injecting capacity. The flow was fixed 0.6 mL per min, and the column's heat was maintained at 40 °C. Analysis completed within a 5 min run time, ensuring efficient and precise quantification.

Preparation of the mobile phase and sample dilution

To eliminate any dissolved gases, the HPLC-grade combination of acetonitrile as well as water (65:35, v/v) is thoroughly blended and gently subjected to sonication for 15 min.

Preparation of standard solution

A dry, clean, and precisely weighed 250 mL volumetric flask was employed for preparing the standard solution. The flask contained 170.9 mg of dinotefuran, 274.3 mg of pyriproxyfen, and 625.4 mg of diafenthiuron. These compounds were dissolved in 100 mL acetonitrile plus 25 mL HPLC water, followed by sonication to ensure complete dissolution. After the solution was fully dissolved and reached ambient temperature, acetonitrile had been

included for the final quantity at 250 mL. It has been sonicated and shaken to ensure uniform mixing. Subsequently, 5 mL from a 250 mL flask's solution were carefully placed into a clean 50 mL volumetric flask and it was made up of diluent.

Sample solution preparation

A precisely weighed 3383.5 mg of the dinotefuran (5%) + pyriproxyfen (8%) + diafenthiuron (18%) SC sample was placed into freshly washed 250 mL volumetric flask. Approximately 5 mL of HPLC water was introduced then the sample was vigorously mixed, followed by sonication to dissolve the solids. Once the solution reached ambient temperature, acetonitrile was introduced to adjust the final volume to the 250 mL mark to ensure complete dissolution of the compounds. The solution was then filtered using a 0.22 µm syringe filter. After filtration, 5 mL from filtrate had been transferred to a 50 mL volumetric flask and make up to the mark from the appropriate diluent.

Development and refinement of chromatographic parameters

The procedure involved establishing and refining separation parameters for the concurrent estimation of dinotefuran, pyriproxyfen, along with diafenthiuron, posed an analytical challenge, requiring a comprehensive approach to managing key factors such as system pressure, resolution efficiency, peak clarity, and retention time consistency. This required methodical evaluation and systematic adjustments to achieve consistent and reproducible results.

For the stationary phase, extensive trials were conducted using various reversed-phase columns to determine the best fit for high-performance separation. The Shim-pack GIST-HP (2.1 mm × 50 mm, 1.9 µ) column was ultimately selected due to its exceptional resolution capabilities for the active compounds, ensuring clear and symmetrical peak profiles under optimized conditions. This decision was the result of iterative testing to refine the parameters for peak shape and separation quality.

Selecting the composition of the mobile phase was another critical aspect, considering the distinct chemical properties and polarities of the analytes. Multiple combinations were explored to achieve ideal separation and resolution. Adjustments to the proportion of acetonitrile in the mixture showed improved elution efficiency but introduced complications such as increased peak asymmetry. The final mobile phase, consisting of acetonitrile as well as purified water in a 65:35 (v/v) proportion, offered the best compromise between separation clarity, peak tailing, and retention characteristics.

Column temperature optimization played a vital role, with experiments carried out with settings which varied between 25 °C and 45 °C. A selected temperature for 40 °C was identified as the optimal setting for achieving stable and efficient separation across all compounds. Similarly, flow rate experiments ranging from 0.3 - 1.5 mL/min confirmed that flow rate of 0.6 mL per min provided a balanced approach to minimizing analysis time while maintaining effective resolution.

The detection wavelength was optimized using a photodiode array detector, ensuring enhanced sensitivity and accuracy. Following detailed evaluation, 240 nm was identified as the wavelength providing the highest absorbance for all three analytes. The final method delivered retention times of 0.29 min, 2.45 min, and 3.70 min for dinotefuran, pyriproxyfen, and diafenthiuron, respectively, with consistent results across multiple trials. Importantly, the optimized chromatographic conditions produced clear and well-defined peaks, avoiding common issues such as broadening, fronting, or tailing.

This rigorous development process demonstrates the precision and systematic effort required to design a robust analytical method for the simultaneous quantification of these active ingredients. By integrating comprehensive testing with targeted optimization, the resulting chromatographic conditions ensure high reliability, efficiency, and reproducibility for agrochemical quality control applications.

Validation of Analytical Method

System performance evaluation

A total of six replicates of a standard solution containing dinotefuran, pyriproxyfen, and diafenthiuron have been injected to assess the appropriateness of method. The appropriateness of the proposed analytical approach was evaluated based on parameters like separation efficiency, RSD, peak symmetry, and elution time.

Specificity

To examine possible interferences from formulation components, present in agrochemical products, a specificity analysis was carried out. The three agrochemical dinotefuran, pyriproxyfen, and diafenthiuron were analyzed, and the results were compared using chromatographic profiles of the standard, sample, formulation ingredients, and solvent.

Linearity

Ten linear concentration levels (parts per million) ranging from Level 1 - Level 10 were prepared for dinotefuran (13.67 - 136.72 ppm), pyriproxyfen (21.94 - 219.44 ppm), and diafenthiuron (50.03 - 500.32 ppm) within a standard solution to evaluate linearity experiment. A calibration curve had been generated by illustrating their peak area towards corresponding concentration levels.

Precision

This study entailed testing 6 solutions using one batch having a combined mixture and comparing them to the reference standard solution in the same day as well as the

days after that, employing assessing overall intra-day and inter-day variability. The %RSD for every substance was estimated utilizing an adapted Horwitz equation.

Accuracy

The accuracy has been employed through spiking methods to determine the recovery rate of dinotefuran, pyriproxyfen, and diafenthiuron. Placebo samples of the respective formulations were analyzed in a chromatographic system with standard solutions at 50%, 100%, as well as 150% concentrations. Every STD solution has been prepared in triplets as well as tested to ensure consistency.

Robustness

Various aspects associated with the newly established method were strategically changed to assess the consistency. The composition of the mobile phase was adjusted from 63% - 77%, with column's heat fluctuating between 39 ˚C and 41 ˚C, and the wavelength varying from 239 nm to 241 nm. Furthermore, the flowrate had been raised from 0.5 - 0.7 mL per min.

Limit of detection (LOD) and limit of quantification (LOQ)

Tests have been conducted to determine the detection and quantification thresholds for dinotefuran, pyriproxyfen, and diafenthiuron at signal-to-noise ratios with 3:1 and 10:1, respectively.

Results

In order to verify that the process complied with SANCO [17] criteria for its intended use, the method was validated.

System suitability

Dinotefuran, pyriproxyfen, and diafenthiuron exhibited retention times of 0.29, 2.45, and 3.70 min, respectively. The tailing factors for these compounds were 1.821, 1.342, and 1.247, all satisfying the acceptable limit of ≤2.0. The %RSD of peak areas (n = 6) was 0.32, 0.46, and 0.55, respectively, all well within the permissible threshold of ≤2.0 (Table 1). The resolution values obtained were 15.42 and 6.55, both exceeding the minimum required value of ≥2.0 [17-23].

Specificity

The selectivity of the proposed approach is evidenced by the lack of substantial interference across the diluent placebo over retention time of dinotefuran (0.29 min), pyriproxyfen (2.45 min), and diafenthiuron (3.70 min), as illustrated in figure 2.

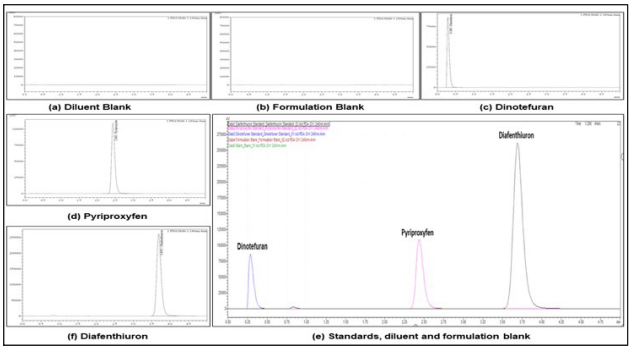


Figure 2: Specificity chromatograms.

Linearity

Dinotefuran, pyriproxyfen, and diafenthiuron display near-perfect correlation coefficients of 0.99999, 0.99998, and 0.99999, respectively, derived from their respective calibration curves. An overview of the data is provided in figure 3.

Precision

Assessing this method's precision, particularly throughout aspects both intra-day and inter-day consistency, seems crucial in this investigation. To evaluate intraday precision, three separate sample preparations were analyzed from exactly one day. For inter-day precision, three new sample preparations were analyzed on different days, using different columns. Percentage standard deviation values associated with both intra-day and inter-day precision across dinotefuran, pyriproxyfen and diafenthiuron presented on table 2.

Accuracy

In order to evaluate the effectiveness of enhanced procedures, spiking methods were employed in dinotefuran, pyriproxyfen, and diafenthiuron at three different concen-

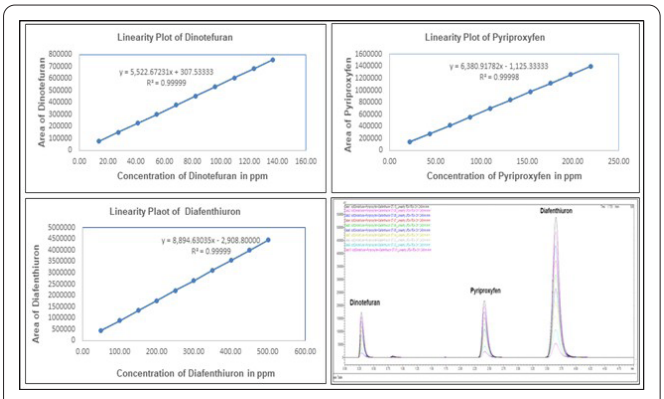


Figure 3: Linear calibration curves with standard chromatograms.

Table 1: System suitability study of dinotefuran, pyriproxyfen and diafenthiuron.

S no.	Parameters	Dinotefuran	Pyriproxyfen	Diafenthiuron	Criteria
1	Retention time (Minute)	0.29	2.45	3.70	-
2	Tailing factor	1.821	1.342	1.247	≤ 2.0
3	% RSD of peak areas	0.32	0.46	0.55	≤ 2.0
4	Resolution	15.43		6.55	≥ 2.0

Table 2: Results of precision method.

Results	Dinotefuran 5 %		Pyriproxyfen 8%		Diafenthiuron 18%	
	Intra-day	Inter-day	Intra-day	Inter-day	Intra-day	Inter-day
Average active content (% w/w)	5.38	5.37	8.27	8.55	18.17	18.41
% RSD	0.10	0.39	0.21	0.28	0.13	0.39
% Criteria	2.10		1.96		1.73	

trations (50%, 100%, and 150%). The results were compared with those of the reference solution to confirm the accuracy of the proposed RP-UFLC technique. The concentration in analysts' peak was compared with a std solution to evaluate the effectiveness of the developed methods.

For dinotefuran, the recoveries were 99.9% at 50%, 99.85% at 100%, and 100.07% at 150%, all falling within the 90 - 110% acceptance range [17]. Pyriproxyfen showed recoveries of 99.97%, 99.98%, and 99.97% at 50%, 100%, and 150% concentrations, respectively, all within the 90 - 110% acceptance criteria [17]. Diafenthiuron exhibited recoveries of 99.75% at 50%, 99.94% at 100%, and 100.0% at 150%, all within the stricter 97 - 103% range [17].

Robustness

To assess the robustness of the proposed methodology, slight modifications were made to the procedure, focusing on the separation of dinotefuran, pyriproxyfen, and diafenthiuron. The flow rate of the column was adjusted between 0.5 and 0.7 mL/min to observe these consequences. Column heat has been initially raised to 41 °C and then reduced to 39 °C to further evaluate temperature impacts. Changes were also modified into the ratio of the organic phase as well as buffer, adjusting from 67:33 v/v - 63:37 v/v, respectively. Additionally, the wavelength (λ) was varied between 239 and 241 nm to evaluate how the system performed across various conditions. Under these modified parameters every peak like dinotefuran, pyriproxyfen and diafenthiuron separated clearly, and the order of elution was consistent. The outcomes of these evaluations are shown in table 3.

LOD and LOQ

The LOD and LOQ evaluate sensitivity of the method. The LOD values were identified for dinotefuran, pyriproxyfen, and diafenthiuron as 0.85 mg/l, 0.90 mg/l, and 2.06 mg/l, correspondingly, while the LOQ were calculated as 1.71 mg/l, 2.74 mg/l, and 2.65 mg/l (Table 4).

Discussion

Referred to as techniques, such as GC, HPLC and LC-MS, have proven to be extremely successful at detecting low level compounds [24-26]. Numerous advancements in food technology have been developed to ensure quality and safety monitoring [27]. For effective quality control of agrochemical products, there is a need for tools that are standardized, rapid, and capable of delivering highly precise results. While researchers have developed analytical methods focusing on single analytes, including dinotefuran, pyriproxyfen, and diafenthiuron [10, 13-15], no comprehensive method exists for the simultaneous evaluation of dinotefuran, pyriproxyfen and diafenthiuron. The described RP-UFLC method enables efficient and reliable analysis of dinotefuran, pyriproxyfen, and diafenthiuron across a wide range of sample types. It is well-suited for the simultaneous quantification of these active ingredients in technical-grade materials, finished formulations, and environmental or residue matrices, including water, fruits, and vegetables. This broad applicability enhances its value for comprehensive agrochemical monitoring. The method's rapid 5 min runtime, minimal solvent use, and excellent chromatographic separation significantly improve operational efficiency. Its perfor-

Table 4: LOD and LOQ findings.

Parameter	Dinotefuran	Pyriproxyfen	Diafenthiuron
LOD (mg/l)	0.78	1.39	3.06
LOQ (mg/l)	1.70	3.44	6.03

Table 3: Robustness study's findings.

S no	Modification to the method parameter	Dinotefuran		Pyriproxyfen		Diafenthiuron	
		Percentage	Effect on outcome	Percentage	Effect on outcome	Percentage	Effect on outcome
1	As such	5.37	-	8.41	-	18.29	-
2	Wavelength 239 nm	5.13	No	8.52	No	18.49	No
3	Wavelength 241 nm	5.15	No	8.38	No	18.51	No
4	Flow-rate 0.5 mL/ min	5.14	No	8.16	No	18.54	No
5	Flow-rate 0.7 mL/ min	5.14	No	8.46	No	18.51	No
6	Column-temperature 39 °C	5.16	No	8.50	No	18.61	No
7	Column-temperature 41 °C	5.14	No	8.61	No	18.68	No
8	Organic phase 63%	5.18	No	8.44	No	18.66	No
9	Organic phase 67%	5.13	No	8.46	No	18.51	No
Average		5.15		8.44		18.58	
RSD		0.33		1.57		0.40	

mance characteristics including high precision, accuracy, and reproducibility meet regulatory expectations and make it suitable for both quality control and field residue testing. Furthermore, the method is cost-effective and environmentally friendly, supporting sustainable laboratory practices. Its versatility in handling multiple matrices and compound forms through a single, robust protocol makes it ideal for widespread adoption in agrochemical, food safety, and environmental sectors. By offering enhanced sensitivity, reduced analysis time, and consistent results, this approach addresses the critical need for high-throughput, multi-residue analysis in modern agricultural and environmental surveillance systems.

Conclusion

Quality is given top priority in the monitoring processes of the food and agrochemical sectors. Conventional analytical methods often require considerable time, resources, and manpower, limiting their overall efficiency. In contrast, simultaneous determination techniques offer a cost-effective and time-saving alternative, delivering significant economic and operational advantages. The proposed RP-UFLC method demonstrates excellent applicability across a wide range of matrices including technical-grade substances, finished formulations, and environmental or residue samples such as water, fruits, and vegetables. All validation parameters comply with SANCO guidelines, confirming the method's reliability for regulatory and industrial use. It has proven to be straightforward, precise, and robust, with the ability to analyze complex samples efficiently even in the presence of interfering additives. This enables rapid processing of high sample volumes without compromising accuracy. Moreover, the method supports sustainable laboratory practices by minimizing solvent usage and waste generation. Its eco-friendly profile, combined with analytical versatility and performance, makes it an ideal solution for modern requirements in agrochemical, food safety, and environmental monitoring sectors.

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Conflict of Interest

None.

References

1. Sebastian A, Nangia A, Prasad MNV. 2020. Advances in agrochemical remediation using nanoparticles. *Agrochem Detect Treat Remediat* 18: 465–485. https://doi.org/10.1016/b978-0-08-103017-2.00018-0
2. De-Assis MP, Barcella RC, Padilha JC, Pohl HH, Krug SBF. 2021. Health problems in agricultural workers occupationally exposed to pesticides. *Rev Bras Med Trab* 18(3): 352-363. https://doi.org/10.47626/1679-4435-2020-532
3. Yang G, Tang Y, Liu X, Wang L, Qin L, et al. 2024. Determination of free glycidol and total free monochloropropanediol in fish and krill oil with simple aqueous derivatization and high-performance liquid chromatography–tandem mass spectrometry. *Foods* 13(15): 2340. https://doi.org/10.3390/foods13152340
4. Simon-Delso N, Amaral-Rogers V, Belzunces LP, Bonmatin JM, Chagnon M, et al. 2014. Neonicotinoid pesticides. Trends, uses, and modes of action of metabolites. *Environ Sci Pollut Res* 22(1): 5-34.
5. Yin J, Liu T, Fang J, Fang K, Zheng L, et al. 2023. The fate, acute, and subchronic risks of dinotefuran in the water-sediment system: a systematic analysis at the enantiomer level. *J Hazard Mater* 443: 130279. https://doi.org/10.1016/j.jhazmat.2022.130279
6. Sullivan JJ, Goh KS. 2008. Environmental fate and properties of pyriproxyfen. *J Pestic Sci* 33: 339–350. https://doi.org/10.1584/jpestics.R08-02
7. Kumari P, Duhan A, Rani N, Tomar D. 2021. Ultimate fate and toxicological consequences of insecticide pyriproxyfen and its metabolites in soil ecosystem. *Environ Adv* 4: 100040. https://doi.org/10.1016/j.envadv.2021.100040
8. Stanley J, Chandrasekaran S, Preetha G, Kuttalam S. 2010. Physical and biological compatibility of diafenthiuron with micro/macro nutrients fungicides and biocontrol agents used in cardamom. *Arch Phytopathol Plant Prot* 43(14): 1396–1406. https://doi.org/10.1080/03235400802476617
9. Bellisai G, Bernasconi G, Brancato A, Cabrera LC, Castellan I, et al. 2022. Review of the existing maximum residue levels for pyriproxyfen according to article 12 of regulation (EC) No 396/2005. *EFSA J* 20(11): e07617. https://doi.org/10.2903/j.efsa.2022.7617
10. Rahman MM, Abd El-Aty AM, Kabir MH, Chung HS, Lee HS, et al. 2018. A quick and effective methodology for analyzing dinotefuran and its highly polar metabolites in plum using liquid chromatography-tandem mass spectrometry. *Food Chem* 239: 1235–1243. https://doi.org/10.1016/j.foodchem.2017.07.073
11. Li R, Liu T, Cui S, Zhang S, Yu J, et al. 2017. Residue behaviors and dietary risk assessment of dinotefuran and its metabolites in *Oryza sativa* by a new HPLC–MS/MS method. *Food Chem* 235: 188–193. https://doi.org/10.1016/j.foodchem.2017.04.181
12. Khalil RE, Shaheen FA, Abd-El Hady AA, Saleh AA. 2024. Quantitative analysis of some insecticide residues using QuEChERS methodology on pepper (*Capsicum annuum*) fruits under greenhouse conditions. *J Plant Prot Pathol* 15(9): 257–265. https://doi.org/10.21608/jppp.2024.300634.1244
13. Mujahid M, Latif S, Ahmed M, Shehzadi W, Imran M, et al. 2022. Modified matrix solid phase dispersion-HPLC method for determination of pesticide residue in vegetables and their impact on human health: a risk assessment. *Front Chem* 10: 1-13. https://doi.org/10.3389/fchem.2022.1084350
14. Chen X, Dong F, Liu X, Xu J, Li J, et al. 2012. Enantioselective separation and determination of the dinotefuran enantiomers in rice, tomato and apple by HPLC. *J Sep Sci* 35(2): 200–205. https://doi.org/10.1002/jssc.201100823
15. Hafeez A, Tawab IA, Iqbal S. 2016. Development and validation of an HPLC method for the simultaneous determination of fipronil, chlorfenapyr, and pyriproxyfen in insecticide formulations. *J AOAC Int* 99(5): 1185–1190. https://doi.org/10.5740/jaoacint.16-0108
16. Stanley J, Chandrasekaran S, Preetha G, Kuttalam S, Jasmine RS. 2016. Selective toxicity of diafenthiuron to non-target organisms: honey bees, coccinellids, chelonus, earthworms, silkworms and fish. *J Plant Prot Res* 56(1): 1–5. https://doi.org/10.1515/jppr-2016-0001
17. European Commission Directorate General Health and Consumer Protection. 2019. Guidance for generating and reporting methods of analysis of technical material and preparations. SANCO/3030/99 rev.5.
18. Panchal J, Dhalani J. 2023. Novel ultra-fast liquid chromatography method for simultaneous quantification of metformin hydrochloride

and remogliflozin etabonate. *Asian J Chem* 35: 1757–1760. https://doi.org/10.14233/ajchem.2023.27910

19. Singh R, Dhaduk B, Dhalani J. 2023. A rapid quantification method for simultaneous determination of pendimethalin and metribuzin contents in suspoemulsion formulation. *Results Chem* 5: 100779. https://doi.org/10.1016/j.rechem.2023.100779
20. Shah T, Dhalani J. 2023. Determination of four novel process-related genotoxic impurities in olmesartan medoxomil tablet by RP-HPLC. *Rasayan J Chem* 16(3): 1543–1552. https://doi.org/10.31788/rjc.2023.1638443
21. Singh R, Jani D, Sharma A, Dhalani J. 2024. A simple and quick run time RP-HPLC method for simultaneous analysis of pyrazosulfuron ethyl and pretilachlor content in GR formulation. *Res J Chem Environ* 28(9): 59–66. https://doi.org/10.25303/289rjce059066
22. Singh R, Dhalani J. 2023. A simple and quick run time RP-HPLC technique for combined analysis of sulfentrazone and clomazone herbicides. *Rasayan J Chem* 16(4): 2154–2162. https://doi.org/10.31788/rjc.2023.1648441
23. Singh R, Dhalani J. 2025. A simple and expeditious RP-HPLC method for the simultaneous determination of commercially available seven pesticide formulations. *Microchem J* 208: 112292. https://doi.org/10.1016/j.microc.2024.112292
24. Song H, Liu J. 2018. GC-O-MS technique and its applications in food flavor analysis. *Food Res Int* 114: 187–198. https://doi.org/10.1016/j.foodres.2018.07.037
25. New LS, Schreiber A, Stahl-Zeng J, Liu H. 2018. Simultaneous analysis of multiple allergens in food products by LC-MS/MS. *J AOAC Int* 101(1): 132–145. https://doi.org/10.5740/jaoacint.17-0403
26. Zhang R, Wang M, Zhu T, Wan Z, Chen X, et al. 2024. Wireless charging flexible *in-situ* optical sensing for food monitoring. *Chem Eng J* 488: 150808. https://doi.org/10.1016/j.cej.2024.150808
27. Zhang R, Wang M, Liu P, Zhu T, Qu X, et al. 2024. Flexible Vis/NIR sensing system for banana chilling injury. *Postharvest Biol Technol* 207: 112623. https://doi.org/10.1016/j.postharvbio.2023.112623