Research Institute of Food Science and Technology

Journal homepage: https://journals.rifst.ac.ir

Research and Innovation in Food Science and Technology

2025; 14(2), 113-128

https://doi.org/10.22101/JRIFST.2025.499861.1609

JRIFST

Review paper

eISSN: 3060-6640

# A Comprehensive Review of Pesticide Elimination Methods from Fruits and Vegetables Over the Past Two Decades: Optimizing Produce Safety for Sustainable Food Systems

**Zoubeida Meghlaoui**[a,*], **Hocine Remini**[b], **Yasmine Remini-Sahraoui**[c], **Mohamed Khalil Mellal**[a], **Sofiane Boudalia**[d], **Yasmine Brahimi**[a], **Samira Negrichi**[a], **Ayoub Allam**[e], **Lamia Medouni-Haroune**[a], **Lynda Messaoudene**[a], **Amina Abbou**[a], **Amokrane Mahdeb**[f], **Nassim Brahimi**[a], **Meriem Amrane-Abider**[a], **Zahia Brara**[a], **Khodir Madani**[a]

[a] Research Center in Agri-Food Technologies, Targa Ouzemmour Road, University Campus, 06000 Bejaia, Algeria
[b] Department of Biology, Faculty of Natural and Life Sciences and Earth Sciences, University of Bouira, 10000 Bouira, Algeria
[c] Department of Biology, Faculty of Sciences, University of Boumerdes, 35000 Boumerdes, Algeria
[d] Laboratory of Biology, Water and Environment, University of May 8th, 1945 Guelma, P.O. Box 401, 24000 Guelma, Algeria
[e] Department of Biological Sciences, Faculty of Natural and Life Sciences, University of Relizane, Relizane, Algeria
[f] Mountain Agro-Systems Division, INRAA: OUED-GHIR Bejaia, 06120, Algeria

## Abstract

The increasing use of pesticides in agriculture, valued at approximately 43.2 billion USD, has raised significant concerns regarding food safety and human health. This study reviews the effectiveness of various pesticide residue removal methods applied to fruits and vegetables (F & V). A total of 57 studies published between 2005 and 2022 were analyzed, categorizing the methods into 28 household techniques, 19 advanced methods, and 10 combined approaches. Household methods, such as washing under running water, achieved removal rates of up to 90%, while peeling ensured complete (100%) elimination of residues. The addition of salt or vinegar solutions improved removal efficiency, reaching 92%. Advanced methods, notably ozonation, demonstrated high efficacy with up to 95% removal. The most effective approaches were combined techniques, integrating washing, ultrasound, and ozonation, which achieved residue elimination rates of up to 99%. Despite their efficiency, advanced methods face limitations due to high costs and technological constraints, reducing their accessibility for widespread use. This review underscores the necessity of an integrated approach to enhance food safety. Additionally, it highlights the need for further research on the long-term impact of these removal methods on the nutritional quality of F & V. These findings provide essential insights for consumers, farmers, and the food industry, contributing to the development of more effective and practical food safety strategies.

**Keywords**
Advanced technique
Decontamination
Fruit
Household method
Vegetable

Received: 19 January 2025 3
Revised: 06 April 2025
Accepted: 21 April 2025
Available online: 23 April 2025

**How to cite:** Meghlaoui, Z., Remini, H., Remini-Sahraoui, Y., Mellal, M. K., Boudalia, S., Brahimi, Y., Negrichi, S., Allam, A., Medouni-Haroune, L., Messaoudene, L., Abbou, A., Mahdeb, A., Brahimi, N., Amrane-Abider, M., Brara, Z., & Madani, K. (2025). A Comprehensive Review of Pesticide Elimination Methods from Fruits and Vegetables Over the Past Two Decades: Optimizing Produce Safety for Sustainable Food Systems. *Research and Innovation in Food Science and Technology*, 14(2), 113-128. https://doi.org/10.22101/JRIFST.2025.499861.1609

## Introduction

The increasing production of fruits and vegetables (F & V) has significantly contributed to food security and economic sustainability over the past two decades, with reported increases of 55 and 65% in production, respectively (FAO, 2021). However, this surge has been accompanied by a dramatic rise in pesticide usage, which reached 3.54 million tons with an expenditure of approximately 43.2 billion USD in 2021 (FAO, 2021; Statista, 2023). While pesticides are vital for controlling harmful organisms that threaten crop yields, their residues in F & V raise serious health concerns for consumers (Megawati *et al.*, 2022; Wang *et al.*, 2022; Majumder *et al.*, 2023). The health risks associated with pesticide residues (PR) are multifaceted and significant. Chronic exposure to low levels of these residues has been linked to endocrine

---

[a] Centre de Recherche en Technologies Agroalimentaires, Route de Targa Ouzemmour, Campus Universitaire, 06000 Bejaia, Algérie
[b] Département de Biologie, Faculté des Sciences de la Nature et de la Vie et des Sciences de la Terre, Université de Bouira, 10000 Bouira, Algérie
[c] Département de Biologie, Faculté des Sciences, Université de Boumerdes, 35000 Boumerdes, Algérie
[d] Laboratoire de Biologie, Eau et Environnement, Université 8 Mai 1945 Guelma BP 401, Guelma 24000, Algérie
[e] Département des sciences biologiques, Faculté des sciences de la nature et de la vie., Université de Relizane, Relizane, Algeria
[f] Division Agrosystèmes de montagne INRAA:OUED-GHIR Bejaia 06120, Algérie

* Corresponding author (zoubeida.meghlaoui@crtaa.dz)

disruption, carcinogenicity, neurotoxicity, and immune toxicity (Tudi *et al.*, 2022; Kalyabina *et al.*, 2021). Although PR levels in F & V generally comply with safety standards set by Maximum Residue Levels (MRLs), exceeding these limits can lead to adverse health effects, particularly among vulnerable populations such as children (El-Sheikh *et al.*, 2022; Forkuoh *et al.*, 2018). Alarmingly, some studies indicate health impacts even at doses deemed safe by regulatory authorities (Aiassa *et al.*, 2019), underscoring the complexity of ensuring food safety amidst rising pesticide use. Despite these challenges, F & V are essential components of a balanced diet, associated with numerous health benefits including reduced risks of cardiovascular disease, diabetes, and certain cancers (Ahn-Jarvis *et al.*, 2019; Aune *et al.*, 2017; Głąbska *et al.*, 2020; Mebdoua, 2018; Gao *et al.*, 2023). Therefore, it is crucial to explore effective methods for minimizing PR while promoting the consumption of these nutritious foods. Various techniques have been investigated for removing PR from F & V, ranging from household methods like washing and peeling to advanced techniques such as ozonation and cold plasma treatment (Anbarasan *et al.*, 2022; Arowolo *et al.*, 2022; Bonnechère *et al.*, 2012). The effectiveness of these methods can vary significantly based on factors such as the type of pesticide used, the characteristics of the produce, and environmental conditions (Wang *et al.*, 2022; Majumder *et al.*, 2023). Consequently, developing a universal solution for PR elimination remains a public health priority.

Unlike previous studies that focus on isolated methods, this review provides a comparative analysis of multiple approaches, considering their effectiveness, scalability, and impact on food quality. It also identifies key knowledge gaps, offering new insights for safer and more practical pesticide residue removal strategies. This comprehensive review aims to critically assess existing physical, chemical, and integrated approaches for reducing pesticide residues (PR) in fruits and vegetables (F & V). Specifically, it seeks to:

- **Evaluate the efficacy** of various PR removal methods, including household, advanced, and combined methods.
- **Analyze the limitations** of these techniques in terms of cost, practicality, environmental, health impact, and potential effects on the nutritional and sensory qualities of F & V.
- **Identify knowledge gaps** in the current research on PR removal, particularly regarding the effectiveness of emerging technologies and their applicability to different pesticide classes and produce types.
- **Propose scalable and sustainable solutions** for reducing PR in F & V, considering feasibility for both consumers and food industries.

## Literature search and analysis method

To gather publications on post-harvest methods for removing or reducing pesticide residues (PR) from F & V, a systematic search was carried out across several databases, including Web of Science and Scopus. In the identification stage, a combination of keywords, synonyms, related terms, and variations was used with the Boolean operators "OR" and "AND". The search included terms like "pesticide", "organochlorine", "organophosphorus", "pyrethroids", "carbamate", "elimination", "removal methods", "fruits", "vegetables", "Washing", "advanced methods", "household methods", "ozone", and "ultrasound". All identified citations were entered into Zotero 7.0.8 (64 bit). Duplicate entries were then eliminated, keeping only the relevant articles. Moreover, the research was focused on coverage of pertinent literature from 2005 to 2022.

To analyze trends in the literature and provide context within global F & V production and pesticide use, keywords were extracted from the 57 selected studies, allowing us to track the evolution of research topics on post-harvest PR methods over time.

## Usage and application of pesticide in agriculture: retrospective trends, classification and contamination risks in fruits and vegetables

The use of pesticides plays an essential role in agriculture by reducing crop losses and increasing yield (Aktar *et al.*, 2009; Strassemeyer *et al.*, 2017). According to the FAO (2021), the thirty leading nations in F & V production account for approximately 85% of global production. As illustrated in Fig. (1), disparities were found in the pesticide use trends among different geographic regions and farming systems. Moreover, the existence of heterogeneous reporting mechanisms and methodological approaches in numerous nations presents a substantial obstacle in terms of evaluating and examining worldwide patterns.

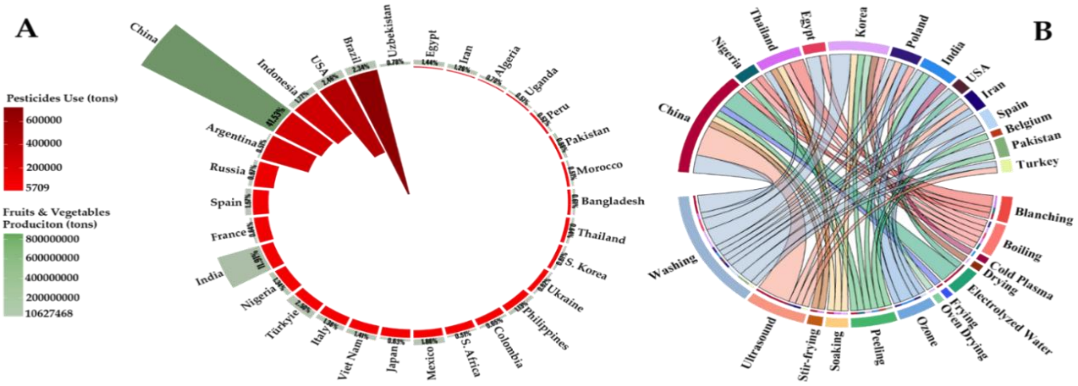

**Fig. 1.** Overview of Pesticide Removal Methods and Use in Global Fruit and Vegetable Production: **(A)** Mirrored radial plot showing global leaders in fruit and vegetable production and their pesticide usage. Percentages indicate each country's share of global fruit and vegetable production. **(B)** Global overview of pesticide removal methods in Fruits and Vegetables: Chord Diagram of Paper Contributions by Country: the outer arcs represents both

countries (upper side) and PR methods (bottom side), while the connecting ribbons indicate the number of studies from each country focusing on specific removal techniques (FAO, 2021).

It is evident from the substantial increase in pesticide usage, which doubled between 1990 and 2018 (Olisah & Adams, 2020), that the continued reliance on these chemicals is essential. However, this upward trend raises concerns regarding the sustainability and long-term environmental consequences of such practices (Sharma *et al.*, 2020). While regulatory measures have been implemented to mitigate risks, there are still significant challenges in effectively managing pesticide use. Furthermore, there is a lack of region-specific and context-specific analysis of pesticide use trends, as exemplified by the case of Uzbekistan (Fig. 1A).

Investigations conducted between 2005 and 2022 (Fig. 2) have presented insights into the existence of pesticide residues in freshly harvested F & V. These investigations have shown that the occurrence of pesticide residues varies due to factors such as farming practices, pesticides types, post-harvest handling, and climatic conditions. Notably, vegetables, particularly bulbous, tuberous, and leafy varieties, are more frequently exposed to pesticide residues, compared to fruits, which are more susceptible to pesticide residues. To identify the presence of pesticide remnants, various analytical techniques, such as non-destructive testing and the QuEChERS (*Quick, Easy, Cheap, Effective, Rugged, and Safe*)-based multi-residue approach, have been employed, which have been confirmed by using Gas Chromatography-Mass Spectrometer (GC-MS/MS) and Liquid Chromatography-Mass Spectrometer (LC-MS/MS) techniques. Insecticides and fungicides are typically found as the most commonly encountered pesticide residues (Naman *et al.*, 2022; Yang *et al.*, 2022), with particular emphasis placed on sample preparation and subsequent analysis. To effectively measure the dangers related to pesticide remains and inform decision-making processes, it is crucial to conduct health risk assessments on vegetables and fruits. Additionally, out of the selected studies (57) in this review, a total of 70 pesticides were identified, representing approximately 10% of the pesticide molecules already cataloged by *OpenFoodTox* chemical hazard from 2002 until 2023 (Carnesecchi *et al.*, 2023).

Moreover, as illustrated in Fig. (3), the bump graph illustrates the evolution of the most commonly used keywords since 2005. Between 2005 and 2022, key subject areas in the research on pesticide removal methods for F & V included “Pesticide”, “Pesticide residue”, and “Food Safety”. These keywords were linked to analytical techniques like GC-MS/MS and LC/MS, as well as processing methods such as “Ultrasound”, “Drying process”, and “Sonolytic ozonation”. The changes in color hue from 2005 to 2022 reflect the shifting rankings of these keywords. Furthermore, our analysis indicated that “Household processing” was the most frequently used keyword in 2005, but it declined in prominence over time, while “Electrolyzed water” became increasingly popular as a technique.

From the perspective of developing a more sustainable food systems, the selection of a removal method is dependent on various factors including the nature of the waste, the accessibility of necessary resources, and the ecological consequences (Yang *et al.*, 2022). In addition to these considerations, properties such as consistency, permeability, and susceptibility to water or chemicals introduce a layer of intricacy. The removal methods are categorized into three groups in this review: household techniques, advanced approaches, and an exploration of their combination was undertaken. As shown in Fig. (1B), the use of these techniques (both household and advanced) is correlated with a country's level of development. For example, in Pakistan, common methods include washing and peeling, while in the USA, washing is supplemented by advanced techniques such as electrolyzed water.

## Household methods for removing pesticides from fruits and vegetables

An overview of the most effective household methods by categorizing F & V according to their food group is given in Table (1). In this section, we aim to better understand the potential benefits of household methods, including washing, blanching, peeling, drying, boiling, soaking, frying, and stir-frying, to remove pesticides residues from fruits and vegetables and explore the effectiveness, accessibility, cost-effectiveness, and safety.

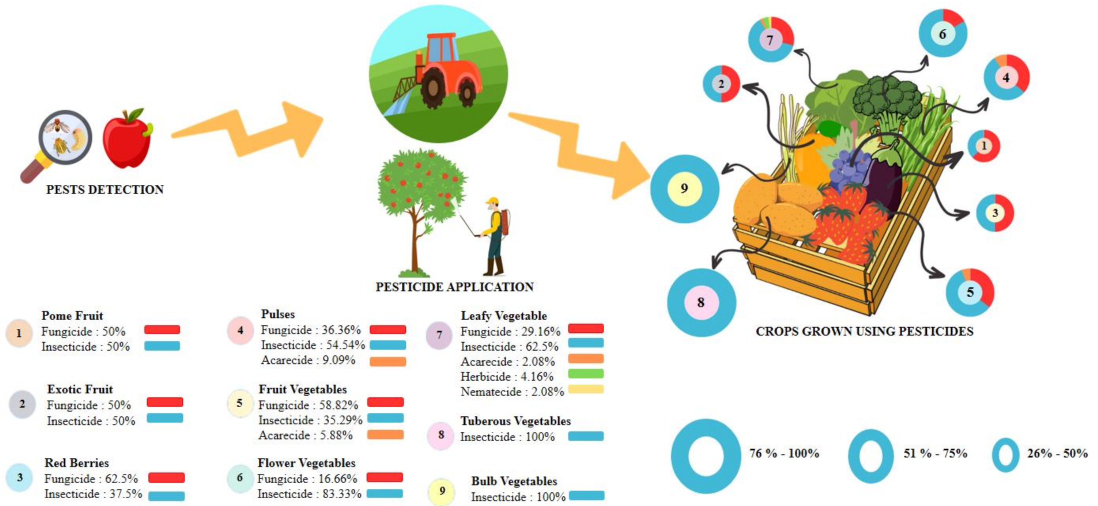

**Fig. 2.** Proportion of pesticide residues in freshly harvested fruit and vegetables (based on selected studies included in this review).

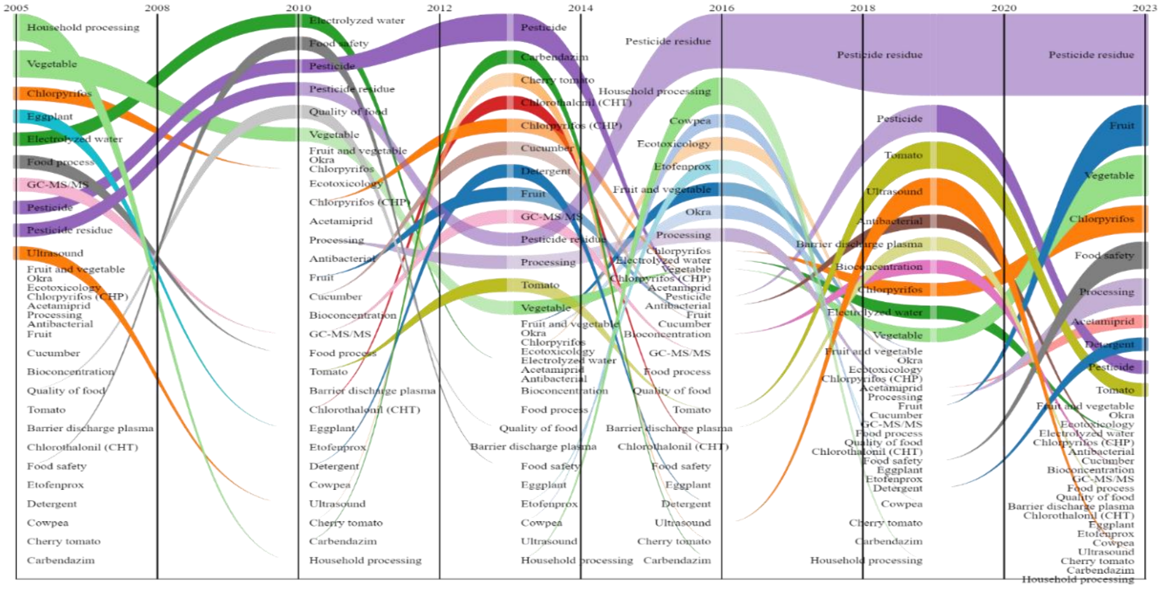

**Fig. 3.** Evolution of research focus in pesticide residues elimination methods from Fruits & Vegetables: A Two-Decades Epic Epoch Plot of Keyword Trends.

**Table 1**. Household methods for removing pesticides from Fruits and vegetables

| No. | Methods | Operating Conditions | Produce | Studied pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| 1 | Washing | Washed for 10 min | Korean melon | Dimethomorph | 58.0 | An *et al.* (2020) |
| | | | | Propamocarb | 31.8 | |
| | | | | Fluopicolide | 31.0 | |
| | | | | Thiamethoxam | 25.6 | |
| | | | | Chlorfenapyr | 22.0 | |
| | | | | Fluopyram | 19.6 | |
| | | | | Dinotefuran | 16.4 | |
| 2 | | Washed under running water for 5 min | Lettuce | Azoxystrobin, Chlorantraniliprole, Chlorfenapyr, Diniconazole, Fludioxonil, Imidacloprid, Indoxacarb, Lufenuron, Pyraclostrobin, Thiamethoxam | 82.5* | Yang *et al.* (2022) |
| | | | Spinach | | 87.7* | |
| | | | Crown daisy | | 78.5* | |
| | | | Perilla leaves | | 76.3* | |
| | | | Ssamchoo | | 59.7* | |
| 3 | | Samples of 50 g are washed at a flow rate of 200 L/h for 15 min | Baby cabbage | Phoxim | 30.7 | Zhang *et al.* (2021) |
| | | | | Chlorothalonil | 20.2 | |
| | | | | Fenarimol | 71 | |
| | | | | Indoxacarb | 65 | |
| | | | | Acetamiprid | 48 | |
| 4 | | The samples were washed in tap water for 5 min | Okra | Chlorfenapyr | 90 | Hanafi *et al.* (2016) |
| 5 | | The samples were washed for 30 seconds with tap water. | Tomato | Chlorpyrifos | 25.23* | Randhawa *et al.* (2007) |
| | | | Cauliflower | | 27.27* | |
| | | | Potato | | 24.03* | |
| | | | Okra | | 21.73* | |
| | | | Spinach | | 20.67* | |
| | | | Eggplant | | 18.10* | |
| 6 | | Washed with tap water for 10 min | Tomato | Thiophanate-methyl | 25 | Liu *et al.* (2021) |
| | | | | Carbendazim | 13 | |
| 7 | | The samples were washed with tap water for 3 min | Cowpea | Chlorothalonil | 31 | Huan *et al.* (2015) |
| | | | | Procymidone | 6 | |
| | | | | Difenoconazole | 0 | |
| | | | | Pyridaben | 0 | |
| | | | | α-Cypermethrin | 0 | |
| | | | | Bifenthrin | 0 | |

**Table 1.** Household methods for removing pesticides from Fruits and vegetables

| No. | Methods | Operating Conditions | Produce | Studied pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| | Soaking | | | S-Fenvalerate | 0 | |
| | | | | λ-Cyhalothrin | 0 | |
| 8 | | Soaked in a detergent solution containing benzalkonium chloride (3%) for 15 min | Tomato | Dichlorvos (DDVP) | 70.7 | Heshmati & Nazemi (2017) |
| 9 | | Samples are soaked with detergent A and 10% acetic acid (pH = 2.27) for 40 min | Cherry tomatoes | Chlorpyrifos | 51 | Wang *et al.* (2013) |
| | | | | Chlorothalonil | 13 | |
| | | The samples were soaked with detergent A and 10% NaCl for 40 min | | Chlorpyrifos | 92 | |
| | | | | Chlorothalonil | 53 | |
| 10 | | Samples were soaked in alkaline water for 5 min | Lettuce | Azoxystrobin, Chlorantraniliprole, Chlorfenapyr, Diniconazole, Fludioxonil, Imidacloprid, Indoxacarb, Lufenuron, Pyraclostrobin, Thiamethoxam | 72.0* | Yang *et al.* (2022) |
| | | | Perilla leaves | | 67.8* | |
| | | | Spinach | | 50.3* | |
| | | | Crown daisy | | 42.0* | |
| | | | Ssamchoo | | 49.9* | |
| | | The samples were soaked in lukewarm water. 5% vinegar, for 5 min | Lettuce | | 65.7* | |
| | | | Perilla leaves | | 58.6* | |
| | | | Spinach | | 51.8* | |
| | | | Crown daisy | | 49.1* | |
| | | | Ssamchoo | | 30.9* | |
| | | The samples were soaked in 2% sodium, bicarbonate, for 5 min | Lettuce | | 66.7* | |
| | | | Perilla leaves | | 63.5* | |
| | | | Crown daisy | | 54.8* | |
| | | | Spinach | | 47.1* | |
| | | | Ssamchoo | | 28.0* | |
| 11 | | Washed with chlorinated tap water in (2 mg/L) tap water at 20 °C for 15 min | Tomato | Dichlorvos (DDVP) | 30.7 | Heshmati & Nazemi (2017) |
| 12 | | The samples were immersed in a FC concentration of 15 mg/L at 22 °C for 10 min | Lettuce | Dimethoate | 46.9 | Yang *et al.* (2022) |
| | | | | Trichlorfon | 37.5 | |
| | | | | Carbofuran | 33.6 | |
| 13 | Mechanical Peeling | Peeled using a knife with a 10 cm blade, a technique commonly used by consumers at home | Melon: Mohican | Maneb | 91 | Bonnechère *et al.* (2012) |
| | | | | Imazalil | 91 | |
| | | | | Acetamiprid | 91 | |
| | | | | Thiamethoxam | 67 | |
| | | | | Carbendazim | 63 | |
| | | | | Cyromazin | 62 | |
| | | | Melon: Pancha | Maneb | 93 | |
| | | | | Imazalil | 91 | |
| | | | | Acetamiprid | 89 | |
| | | | | Thiamethoxam | 58 | |
| | | | | Cyromazin | 52 | |
| | | | | Carbendazim | 47 | |
| 14 | | The peel was removed at a uniform thickness using a filler (KZ-10, Japan) | Korean melon | Propamocarb | 96.6 | An *et al.* (2020) |
| | | | | Dimethomorph | 94.5 | |
| | | | | Fluopicolide | 81.5 | |
| | | | | Dinotefuran | 80.5 | |
| | | | | Thiamethoxam | 79.8 | |
| | | | | Fluopyram | 75.9 | |
| 15 | | Peeled by removing the outer coat with a knife | Tomatoes: Roma | β –Cypermethrin | 48.55 | Arowolo *et al.* (2022) |
| | | | | α-Cypermethrin | 15.14 | |
| | | | | Cyfluthrin | 8.46 | |
| | | | Tomatoes: Roma VF | Cyfluthrin | 100 | |
| | | | | α-Cypermethrin | 100 | |
| | | | | β-Cypermethrin | 10.70 | |
| 16 | | Peeled with a standard household hand peeler (Y- | Apple | Mancozeb | 24.60 | Naman *et al.* (2022) |

**Table 1.** Household methods for removing pesticides from Fruits and vegetables

| No. | Methods | Operating Conditions | Produce | Studied pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| | | type) that removed the peel up to 3 mm thick | | | | |
| 17 | Blanching | Submerging the tomatoes in water at 85 °C for 4 min | Tomatoes: Roma | α-Cypermethrin | 100 | Yang *et al.* (2022) |
| | | | | β-Cypermethrin | 48.23 | |
| | | | | Cyfluthrin | 7.44 | |
| | | | Tomatoes: Roma VF | α-Cypermethrin | 100 | |
| | | | | β-Cypermethrin | 100 | |
| | | | | Cyfluthrin | 0.18 | |
| 18 | | Treated samples were placed in boiling water for 5 min | Eggplant<br>Pepper | Profenofos | ≃100 | Radwan *et al.* (2005) |
| 19 | | Samples were placed in boiling water (100 °C) for 30 seconds. | Lettuce | Azoxystrobin, Chlorantraniliprole, Chlorfenapyr, Diniconazole, Fludioxonil, Imidacloprid, Indoxacarb, Lufenuron, Pyraclostrobin, Thiamethoxam | 68.4* | Yang *et al.* (2022) |
| | | | Perilla leaves | | 56.7* | |
| | | | Ssamchoo | | 52.3* | |
| | | | Spinach | | 49.3* | |
| | | | Crown daisy | | 47.9* | |
| 20 | | The samples were put in boiling water (100 °C) in a container uncovered pot for 3-5 min | Cowpea | Procymidone | <LOQ | Huan *et al.* (2015) |
| | | | | Chlorothalonil | <LOQ | |
| | | | | Difenoconazole | <LOQ | |
| | | | | Pyridaben | 0 | |
| | | | | α-Cypermethrin | 0 | |
| | | | | Bifenthrin | 0 | |
| | | | | S-Fenvalerate | 0 | |
| | | | | λ-Cyhalothrin | 0 | |
| 21 | Oven drying | The samples were oven-dried at 50 °C for 3 days | Apple | Mancozeb | 100 | Naman *et al.* (2022) |
| | | Samples are sun-dried for 20 days | | | 100 | |
| 22 | | The samples were oven-dried at 60 °C for 35 h | Chili peppers | Clothianidin, Diethofencarb, Imidacloprid, Tetraconazol | 37-49 | Yang *et al.* (2022) |
| | | | | Methomyl, Methoxyfenozide | 16-22 | |
| 23 | Boiling | Samples are placed in boiled water at 100 °C for 5 min | Strawberries | Pyraclostrobin | 92.9 | Lozowicka *et al.* (2016) |
| | | | | Cyprodinil | 42.8 | |
| 24 | | Immersing samples in boiled water at 100 °C for 5 min | Lettuce | Azoxystrobin, Chlorantraniliprole, Chlorfenapyr, Diniconazole Fludioxonil, Imidacloprid, Indoxacarb, Lufenuron, Pyraclostrobin, Thiamethoxam | 66.5* | Yang *et al.* (2022) |
| | | | Crown daisy | | 65.9* | |
| | | | Spinach | | 65.6* | |
| | | | Ssamchoo | | 55.4* | |
| | | | Perilla leaves | | 44.0* | |
| 25 | | Boiled tomatoes at 100 °C for 10 min | Tomatoes: Roma | Cyfluthrin | 100 | Arowolo *et al.* (2022) |
| | | | | β –Cypermethrin | 46.61 | |
| | | | | α-Cypermethrin | 14.96 | |
| | | | Tomatoes: Roma VF | β –Cypermethrin | 100 | |
| | | | | α-Cypermethrin | 100 | |
| | | | | Cyfluthrin | 0.36 | |
| 26 | Frying | The samples were cut into 3 cm pieces and added to an open container. wok of peanut oil (210–240 °C) and were fried for 50 seconds | Cowpea | Procymidone | 0 | Huan *et al.* (2015) |
| | | | | Chlorothalonil | 0 | |
| | | | | Difenoconazole | <LOQ | |
| | | | | Pyridaben | <LOQ | |
| | | | | α-Cypermethrin | <LOQ | |
| | | | | Bifenthrin | <LOQ | |
| | | | | S-Fenvalerate | <LOQ | |
| | | | | λ-Cyhalothrin | <LOQ | |
| 27 | | Unwashed fried | Okra | Bifenthrin | 76.9 | Sheikh *et al.* (2012) |
| | | | | Endosulfan | 14.21 | |
| | | Plain-washed fried | | Bifenthrin | 77.3 | |
| | | | | Endosulfan | 42.71 | |
| | | | | Bifenthrin | 78.8 | |
| | | Detergent washed fried | | Endosulfan | 68.41 | |

**Table 1**. Household methods for removing pesticides from Fruits and vegetables

| No. | Methods | Operating Conditions | Produce | Studied pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| 28 | Stir-frying | Samples were cut into 3 cm pieces and added to an open wok of peanut oil (250–280 °C) and stir-fried for 3 min | Cowpea | Procymidone | 0 | Huan *et al.* (2015) |
| | | | | Chlorothalonil | 0 | |
| | | | | Difenoconazole | 0 | |
| | | | | Pyridaben | <LOQ | |
| | | | | α-Cypermethrin | <LOQ | |
| | | | | Bifenthrin | <LOQ | |
| | | | | S-Fenvalerate | <LOQ | |
| | | | | λ-Cyhalothrin | <LOQ | |

* Total elimination rate per produce for all studied pesticide; LOQ: Limit of quantification.

### Washing methods

Among household methods, *washing* has been a major subject of research because it has been an easy-to-do home removing pesticide residue from F & V surfaces. Studies have shown that washing over a long period, particularly with leafy vegetables and okra (>60 and >48% respectively), can lead to a valuable reduction in PR (Hanafi *et al.*, 2016; Randhawa *et al.*, 2007; Yang *et al.*, 2022). However, limitations have been observed, with certain crops such as Korean melon, baby cabbage, cauliflower, tomato, potato, spinach, and eggplant showing lower pesticide reduction (<58, <20.2, 27.27, <25, <24.03, <20.67 and <18.10%, respectively) even after 10 min washing (An *et al.*, 2020; Randhawa *et al.*, 2007; Zhang *et al.*, 2021). Studies reported that washing with tap water and various detergent solutions can improve pesticide reduction (Iizuka & Shimizu, 2014). For example, washing with a 5% sodium carbonate solution resulted in a reduction of trichlorfon and dimethoate pesticides by 97.6 and 78.3%, respectively (Liang *et al.*, 2012). Similarly, a 5% sodium bicarbonate solution led to reductions in dichlorvos, fenitrothion, and chlorpyrifos by 98.8, 66.7, and 85.2%, respectively. Another factor that plays a crucial role in the effectiveness of the washing method is the solubility of pesticides, while certain show notable reductions like Imidacloprid, Chlorpyrifos, Thiabendazole, Diphenylamine, Imazalil, Fludioxonil, and Pyrimethanil (Al-Taher *et al.*, 2013). Dimethoate, Pirimiphos-Methyl, and Malathion were less effectively removed from potatoes. However, the efficacy of pesticide removal can vary based on the specific properties of the produce (Guardia-Rubio *et al.*, 2007; López-Fernández *et al.*, 2013).

In this review, household methods such as washing and soaking in solutions like acetic acid (vinegar) and sodium bicarbonate are discussed, with notable differences in their effectiveness. Acetic acid achieves removal rates of 51% for cherry tomatoes, while sodium bicarbonate demonstrates a broader range of efficacy, removing between 28 and 66.7% of residues from leafy vegetables. The effectiveness of these solutions depends on the type of pesticide and the surface characteristics of the produce. Sodium bicarbonate is particularly efficient in breaking down certain pesticides through alkaline hydrolysis, making it more suitable for pesticide degradation. In contrast, acetic acid primarily works by altering pesticide structures through acidity, which can be beneficial for certain compounds but less effective overall. These differences highlight the importance of selecting appropriate household treatments based on the type of produce and the nature of pesticide residues present. (Heshmati & Nazemi, 2017; Wang *et al.*, 2013; Zhu *et al.*, 2019; Yang *et al.*, 2022).

### Peeling method

Peeling is less commonly used in traditional methods, it has been found to be effective in certain crops such as melons (>62%) and specific tomato varieties (100%). However, the physicochemical properties of pesticides, especially their penetration into the produce, can influence the efficacy of peeling as a removal method (An *et al.*, 2020; Arowolo *et al.*, 2022; Bonnechère *et al.*, 2012; Naman *et al.*, 2022). For instance, peeling is not appropriate for berries to avoid crushing (Sánchez *et al.*, 2012).

### Thermal processing methods

Thermal processing methods, including blanching, oven drying, boiling, frying, and stir-frying, have generally proven effective in reducing pesticide residues in food products. Blanching, for example, has been successful in reducing residues in tomatoes (100%), eggplants, peppers, and cowpea. However, exceptions exist, with certain crops like chili peppers and leafy vegetables which have not shown relevant pesticide elimination through these methods (Arowolo *et al.*, 2022; Huan *et al.*, 2015; Radwan *et al.*, 2005; Naman *et al.*, 2022; Yang *et al.*, 2022).

The effectiveness of thermal processing can be influenced by various factors, including pesticide properties, processing duration, and the lipophilicity of pesticides. Pesticides with high lipophilicity have shown more efficient removal through frying and stir-frying compared to those with low lipophilicity. However, concerns about the concentration and transformation of pesticides during thermal processing highlight the need for careful consideration of safety and quality attributes (Huan *et al.*, 2015; Phopin *et al.*, 2022; Sheikh *et al.*, 2012; Zhang *et al.*, 2007; Zhang *et al.*, 2022). These considerations are particularly relevant in the context of environmental protection and sustainable practices in the food industry (Zhang *et al.*, 2022).

### Household methods limitations

Using household methods for removing pesticides from F & V offers several merits, including easy access methods, and requires minimal effort to implement. The effectiveness in reducing contact pesticide residues, accessibility, cost-effectiveness, and improved safety. While they may have some limitations, as seen in the chosen studies (Table 1), none of these methods exhibit unequivocal efficacy, which will make them a valuable tool for consumers aiming to reduce their exposure to pesticides, mainly for vulnerable populations such as children, pregnant women, and older people. Their effectiveness is contingent upon various factors including the inherent properties of the product, the mode of action of the pesticide employed, and the duration of the treatment process. And then limited efficacy for systemic pesticides: deeply penetrated residues may persist (Arowolo *et al.*, 2022). A combination of household approaches and scrubbing may give better results; further research in this area can help refine these methods and promote their adoption, contributing to healthier food choices and overall well-being.

## Advanced methods for removing pesticides from fruits and vegetables

A variety of novel techniques for removing pesticides from F & V, such as ultrasound, ozone, lye peeling, electrolyzed water, non-thermal (NTP), and cold plasma, have been explored in Table (2). These advanced methods offer additional benefits and potential advantages over traditional household methods in terms of efficacy, precision, and thoroughness, broad-spectrum acting, in addition to reducing time and temperature, which helps preserve heat-sensitive nutrients like vitamins but also limitations such as changes in nutritional characteristics (Zhang *et al.*, 2022).

**Table 2.** Advanced methods for removing pesticides from fruits and vegetables

| No | Methods | Processing condition | Produce | Studied Pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| 1 | Ultrasound | Power mode at 300 W for 15 min, at 25 ± 1 °C | Tomato | Dichlorvos (DDVP) | 88.9 | Heshmati & Nazemi (2017) |
| 2 | | Samples are cleaned in an ultrasonic cleaner (frequency 40 kHz, power 2 × 240W) for 5 min | Strawberry | Pyraclostrobin<br>Tetraconazole<br>Chlorpyrifos | 89.4<br>84.5<br>79.1 | Lozowicka *et al.* (2016) |
| 3 | | Multi-frequency multi-mode ultrasound treatment 'MFMU' Multifrequency mode (20, 40, and 60 kHz) for 8 min | Lettuce | Emamectin benzoate<br>Abamectin b1<br>α -methrin | 95.25<br>92.31<br>89.36 | Azam *et al.* (2021) |
| 4 | | Samples are cleaned in ultrasonic cleaner at 25 kHz, with 500 W at 60 min | Lettuce | Methamidophos Dichlorvos | < 50 | Fan *et al.* (2015) |
| 5 | | Samples were cleaned in the ultrasonic cleaner (40 kHz, 600 W) for 10 min | Lettuce | Dimethoate<br>Trichlorfon<br>Carbofuran | 55.1<br>52.3<br>35.4 | Yang *et al.* (2022) |
| 6 | | Samples are placed in an ultrasonic cleaner at 40 kHz for 5 min | Lettuce<br>Perilla leaves<br>Crown daisy<br>Spinach<br>Ssamchoo | Azoxystrobin, Chlorantraniliprole,Chlorfenapyr, Diniconazole, Fludioxonil, Imidacloprid, Indoxacarb, lufenuron, Pyraclostrobin, Thiamethoxam | 68.0*<br>62.1*<br>52.9*<br>49.7*<br>31.2* | |
| 7 | Ozone | Immersed in ozone water (6 mg/L) for 15 min at 15 °C | Tomato | Dichlorvos (DDVP) | 91.9 | Liu *et al.* (2021) |
| 8 | | The samples were immersed in this solution (20 °C, 1 mg $O_3$/L) for 5 min | Strawberry | Chlorpyrifos<br>Tetraconazole | 75.1<br>36.1 | Lozowicka *et al.* (2016) |
| 9 | | Ozone output of 200 mg/h, and pressure (0.50 kg/cm$^2$) for 3 min | Okra<br>Chili | Acetamiprid<br>Ethion | 39.2-59.5<br>24.2-51.4 | Singh *et al.* (2022) |
| 10 | | Samples are placed in the cleaning column generating microbubbles with ≃ 30 µm, at 0.5 MPa at a flow rate of 200 L/h for 15 min | Baby cabbage | Phoxim<br>Chlorothalonil | 67.7<br>59.4 | Zhang *et al.* (2021) |
| 11 | | The samples were treated with $O_3$ at 75 mg/min, for 60 min at 8 °C. | Lettuce | Methamidophos<br>Dichlorvos | 65.58<br>54.64 | Fan *et al.* (2015) |
| 12 | | Infused with 550 mg/L at low pressure (2 mbar) for 6 min | Soybean | Chlorpyrifos | 50 | Anbarasan *et al.* (2022) |
| 13 | Cold Plasma | Cold plasma 2.0 kV for 6 min | Soybean | Chlorpyrifos | 58.95 | |
| 14 | Electrolyzed water | The Dielectric barrier (DBD) system comprises "two circular aluminum plate electrodes (outer diameter 158 mm) + rigid PET package with dimensions of | Strawberries | Fludioxonil<br>Azoxystrobin | 71<br>69 | Misra *et al.* (2014) |

**Table 2.** Advanced methods for removing pesticides from fruits and vegetables

| No | Methods | Processing condition | Produce | Studied Pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| 15 | | $150\times150\times$ 35 mm”. Atmospheric air was the carrier gas, and the voltage used was 80 kV at 50 Hz frequency for 300 seconds | | Pyriproxyfen | 46 | Cong *et al.* (2021) |
| | | | | Cyprodinil | 45 | |
| | | Dielectric barrier (DBD) voltage: atmospheric air was the carrier gas at a voltage of 80 kV for 180 seconds | Lettuce | Malathion | 59.0 | |
| | | | | Chlorpyrifos | 57.9 | |
| 16 | | A 10-g sample of each inoculated vegetable was soaked separately in AcEW | Cabbage (was treated with 3200 mL AcEW) | Cyfluthrin | 82 | Liu *et al.* (2021) |
| | | | | Chlorpyrifos | 78 | |
| | | | | λ-Cyhalothrin | 76 | |
| | | | | Procymidone | 64 | |
| | | | | Phorate | 62 | |
| | | | | Phlorothalonil | 58 | |
| | | | | Cyfluthrin | 74 | |
| | | | Broccoli (treated with 1600 mL AcEW) | Chlorpyrifos | 72 | |
| | | | | λ-Cyhalothrin | 63 | |
| | | | | Phorate | 61 | |
| | | A 10-g sample of each inoculated vegetable was soaked separately in AlEW | Broccoli (treated with 1600 mL AlEW) | Phlorothalonil | 74 | |
| | | | | Procymidone | 70 | |
| | | | Color pepper (treated with 800 mL AlEW) | Phlorothalonil | 78 | |
| | | | | Procymidone | 63 | |
| | | | | Cyfluthrin | 61 | |
| | | | | Phorate | 59 | |
| | | | | λ-Cyhalothrin | 59 | |
| | | | | Chlorpyrifos | 57 | |
| 17 | | All treatments were carried out in a reciprocal shaking bath set at 100 rpm, with available chlorine content (ACC) of 120 mg/L for 15 min | Grapes (200 g per 500 mL) | Phosmet | 49.4 | Qi *et al.* (2018) |
| | | | | Cyprodinil | 37.1 | |
| | | | | Diazinon | 31.5 | |
| | | | Spinach (15g per 1000 mL) | Phosmet | 85.7 | |
| | | | | Diazinon | 59,2 | |
| | | | | Cyprodini | 43.8 | |
| | | | Snap beans (50 g per 500 mL) | Phosmet | 73.0 | |
| | | | | Diazinon | 66.5 | |
| | | | | Cyprodinil | 50.0 | |
| | | Treatment with ER water with 120 mg/L ACC, pH 11.5 for 15 min | Grape | Phosmet | 39 | |
| | | | | Diazinon | 22 | |
| | | | | Cyprodinil | 17 | |
| | | | Spinach | Phosmet | 70 | |
| | | | | Diazinon | 28 | |
| | | | | Cyprodinil | 15 | |
| | | | Snap beans | Phosmet | 76 | |
| | | | | Diazinon | 49 | |
| | | | | Cyprodinil | 30 | |
| 18 | | Electrolyzed oxidizing (EO) water (pH 2.3, available chlorine concentration: 70 ppm, oxidation-reduction potential [ORP]: 1170 mV) for 30 min | Spinach | Acephate | 74 | Hao *et al.* (2011) |
| | | | | Ominethoate | 62 | |
| | | | | Dimethyl Dichlorovinyl Phosphate [DDVP] | 59 | |
| | | Electrolyzed reducing (ER) water (pH 11.6, ORP: (860 mV) for 30 min | | Acephate,<br>Ominethoate, Dimethyl<br>Dichloroviny Phosphate [DDVP] | 86<br>75<br>46 | |
| 19 | Lye peeling | Dipping samples in water at 76 ˚C with a 5% caustic soda (NaOH) solution for 10 min | Tomato | Mancozeb | 37.57 | Naman *et al.* (2022) |

* Total elimination rate per produce for all studied pesticide

### *Ultrasound*

Ultrasound involves the use of high-frequency sound waves (typically above 20 kHz) to create cavitation bubbles in a liquid medium. This physical removal technique breaks down the adhesion between the pesticide molecules and the produce surface, facilitating their removal (Bhargava *et al.*, 2021). However, its effectiveness can vary based on several factors, including the nature of the pesticide and the frequency used. For instance, studies have demonstrated that organophosphorus pesticides can be eliminated through ultrasonication within a 20-minute duration (Liang *et al.*, 2012). The efficacy of ultrasound in removing pesticides from strawberries was found to be dependent on factors such as pesticide characteristics and the frequency of 40 kHz (Lozowicka *et al.*, 2016). However, ultrasound was generally less effective at reducing pesticides in leafy vegetables compared to fruits, with elimination rates ranging from 68 to 31.2% (Fan *et al.*, 2015; Yang *et al.*, 2022), except in the case of lettuce, where it showed a high elimination rate (Azam *et al.*, 2021). Ultrasound has limitations, including the potential degradation of bioactive compounds and adverse effects on sensory and nutritional characteristics (Zhang *et al.*, 2022). Careful optimization is required to minimize any negative impact. Then, treating irregularly shaped or delicate produce remains essential. Moreover, it may not always meet the demands of large-scale applications, and energy input must be considered (Soria & Villamiel, 2010; Patist & Bates, 2008).

### *Ozone*

Ozone is a versatile method for residue removal, it is a reactive oxidizing agent that can break down a wide range, and target multiple pesticide compounds simultaneously from fresh produce. Its efficiency depends on factors such as solubility in water, temperature, pH, and humidity (Díaz-López *et al.*, 2022). Recent studies have shown high pesticide elimination levels in tomatoes (91.9%) using ozone (Liu *et al.*, 2021). However, it may not be highly effective in okra (39.2-59.5%), chili (24.2-51.4%) (Anbarasan *et al.*, 2022; Fan *et al.*, 2015; Singh *et al.*, 2022; Zhang *et al.*, 2021). Ozone is particularly effective in eliminating non-systemic pesticides, as demonstrated in the removal of chlorpyrifos in strawberries (Lozowicka *et al.*, 2016). Treatment parameters optimization is required to not degrade certain beneficial compounds, such as antioxidants or vitamins, present in fruits and vegetables (EPA, 2023). In addition, the treatment is a physical process that does not leave any chemical traces or byproducts in the food it processes. However, its treatment might be more expensive since it requires specialized equipment and trained workers, and can alter the food’s appearance, texture, and taste (Aidoo *et al.*, 2023).

### *Cold Plasma*

Plasma, formed by excited atoms, molecules, and high-energy species, has been used as a removal method for pesticides. It helps preserve the overall freshness of F & V. Studies have observed pesticide elimination ranging from 45 to 71% in strawberries and lettuce using plasma (Cong *et al.*, 2021; Misra *et al.*, 2014). In contrast to ultrasound treatment, the non-contact treatment can act in irregularly shaped or delicate produces without causing damage, if they are not protected by waxy surfaces. However, the lack of studies on pesticide removal from fruits and vegetables using plasma represents a limitation in assessing its effectiveness compared to other innovative methods (Mao *et al.*, 2021)

### *Electrolyzed water*

Electrolyzed water (EW), also known as electrochemically activated water, including oxidizing water (EOW) and electrolyzed reduced water (ERW), is an effective disinfectant in the food industry, which can reduce presence of reactive oxygen species, such as hypochlorous acid (HOCl) and free radicals (Iram *et al.*, 2021). Research on EW has shown consistent pesticide elimination rates in both acidic and alkaline processing conditions and in oxidizing and reducing EW operating conditions (Liu *et al.*, 2021; Hao *et al.*, 2011; Qi *et al.*, 2018). Despite its effectiveness in removing certain pesticide residues, electrolyzed water (EW) has limitations, including reduced efficiency against water-insoluble pesticides, limited penetration into produce surfaces, variable degradation efficacy depending on chlorine species, and potential concerns regarding residual chlorine and equipment corrosion (Qi et al., 2018).

### *Lye peeling*

Lye peeling is less commonly studied advanced methods (Table 2); they have shown relatively low reductions in pesticide levels (Anbarasan *et al.*, 2022). There are some limitations to using lye peeling in removing pesticides from F & V affecting the effectiveness, safety, nutrient loss, and cause environmental impact (Chung, 2018).

### *Advanced methods limitations*

Advanced techniques have demonstrated their ability to effectively eliminate pesticides, mainly with a deep penetration which allows better food safety and consumer confidence, less water consumption, and aligns with stringent regulatory standards and the universal call of the Sustainable Development Goals (GDP 3, 6 and 12). Advanced methods are suitable for industrial-scale operations, facilitating the processing of large quantities of F & V with minimal time and effort. It is essential to underscore that these methods can be costly. The installation, maintenance, and operation of ultrasound systems may not be financially viable for small-scale or resource-limited operations.

Some pesticides may be more resistant to removal by advanced methods, necessitating the exploration of alternative or supplementary methods for complete residue elimination, and have adverse environmental impacts mainly energy-intensive processes. The optimization of treatment parameters is essential to minimizing potential drawbacks.

## Combined methods for removing pesticides from fruits and vegetables

To enhance the elimination of pesticides from produce, numerous studies have ventured into the combined use of two or more removal methods, as detailed in Table (3). These studies consistently indicate that employing a combination of conventional and advanced methods leads to improved rates of pesticide residue removal.

In the case of Chlorpyrifos, a higher elimination rate (>86.53%) was achieved by employing a combination of three traditional household methods, as demonstrated in the

Randhawa *et al.* (2007) study. Similar positive outcomes were observed for okra, where the combination of more than two methods enhanced pesticide elimination (Hanafi *et al.*, 2016). However, for the removal of Thiophanate-Methyl and Carbendazim from tomatoes, effective results were obtained with only two traditional removal methods (Liu *et al.*, 2021). Interestingly, Huan *et al.* (2015) found that the most effective combination for removing pesticides from cowpea involved blanching and stir-frying.

In contrast, the combination of advanced methods has consistently shown more success in reducing pesticides. Ultrasound, when paired with various techniques like $O_3$, Free Chlorine, Electric current, and vortex washing, has exhibited a high level of pesticide elimination (Cengiz *et al.*, 2018; Fan *et al.*, 2015; Siddique *et al.*, 2021; Yang *et al.*, 2022; Zhou *et al.*, 2019). However, it is worth noting that ultrasound combined with electrolyzed water produced less effective results ($<33.8\%$) in terms of pesticide removal, suggesting that this particular combination might not be efficient for removing pesticides from vegetables (Lin *et al.*, 2006).

The challenges associated with assessing the degradation mechanisms of pesticides in combined methods underscore the need for further research and development. A comprehensive understanding of the underlying degradation pathways is crucial to ensure accurate and reliable assessments. Simultaneously, efforts should focus on optimizing the cost-effectiveness of these combined methods, facilitating their wider application in pesticide degradation studies (Zhang *et al.*, 2022). This holistic approach to pesticide removal from produce holds promise for improving food safety and quality.

In summary, numerous studies have highlighted the effectiveness of combining methods to remove pesticides from F & V (Zhang *et al.*, 2022). Nevertheless, certain shortcomings have been observed, making it crucial to gain a comprehensive understanding of the mechanisms behind each method to exercise better control over various parameters.

**Table 3.** Combined methods used for removing pesticides from fruits and vegetables

| No | Combined methods | Operating conditions | Produce | Studied pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| 1 | Washing, Cooking | All samples were washed for 30 s with tap water and then cooked for 10–12 min | Tomato | Chlorpyrifos | 46.72 | Randhawa *et al.* (2007) |
| | | | Spinach | | 49.51 | |
| | | | Okra | | 45.74 | |
| | | | Cauliflower | | 36.36 | |
| | Washing, peeling | After washing potatoes and eggplants, they were hand-peeled | Eggplant | | 88.07 | |
| | | | Potato | | 74.03 | |
| | Washing, peeling, Cooking | After washing the potatoes, the eggplants were hand peel-ed before being cooked in boiling water for 10-12 min | Eggplant | | 90.50 | |
| | | | Potato | | 86.53 | |
| 2 | Washing, Peeling | Washed with tap water for 10 min. Then hand peeled | Tomato | Carbendazim | 87.3 | Liu *et al.* (2021) |
| | | | | Thiophanate-methyl | 84.2 | |
| 3 | Blanching + Stir-frying | Blanched at 100 °C for 5 min and stir-fried at 250–280 °C for 3 min | Cowpea | Procymidone | <LOQ | Huan *et al.* (2015) |
| | | | | Chlorothalonil | <LOQ | |
| | | | | Difenoconazole | <LOQ | |
| | | | | Pyridaben | <LOQ | |
| | | | | α -Cypermethrin | <LOQ | |
| | | | | Bifenthrin | <LOQ | |
| | | | | S-Fenvalerate | <LOQ | |
| | | | | k-Cyhalothrin | <LOQ | |
| | Washing + Stir-frying | Washed with tap water for 3 mins and stir-fried at 250–280 °C for 3 min | | Chlorothalonil | 19 | |
| | | | | Procymidone | 0 | |
| | | | | Difenoconazole | 0 | |
| | | | | Pyridaben | <LOQ | |
| | | | | α -Cypermethrin | <LOQ | |
| | | | | Bifenthrin | <LOQ | |
| | | | | S-Fenvalerate | <LOQ | |
| | | | | k-Cyhalothrin | <LOQ | |
| | Washing + Frying | Washed with tap water for 3 min and stir-fried at 210–240 °C for 50 s. | | Procymidone | 0 | |
| | | | | Chlorothalonil | 0 | |
| | | | | Difenoconazole | <LOQ | |
| | | | | Pyridaben | <LOQ | |
| | | | | α -Cypermethrin | <LOQ | |
| | | | | Bifenthrin | <LOQ | |
| | | | | S-Fenvalerate | <LOQ | |
| | | | | k-Cyhalothrin | <LOQ | |
| 4 | Washing + Boiling | Samples were washed with tap water for 5 min and boiled for 5-7 min | Okra | Chlorfenapyr | 91 | Hanafi *et al.* (2016) |
| | | | | Indoxacarb | 76 | |
| | | | | Acetamiprid | 75 | |
| | | | | Fenarimol | 74 | |
| | Washing + Steaming | Samples were washed with tap water for 5 min and steamed using a traditional steam pot for 3-7 min | | Chlorfenapyr | 81 | |
| | | | | Acetamiprid | 76 | |
| | | | | Indoxacarb | 55 | |

**Table 3.** Combined methods used for removing pesticides from fruits and vegetables

| No | Combined methods | Operating conditions | Produce | Studied pesticides type | Elimination rate (%) | References |
|---|---|---|---|---|---|---|
| | | | | Fenarimol | 52 | |
| | Washing + Chemical boiling | Samples were washed with tap water for 5 min and immersed in a chemical solution: 250 ppm zinc chloride, 0.5% potassium metabisulphite, 0.1% magnesium oxide, and 0.1% sodium bicarbonate for 3 min | | Chlorfenapyr | 85 | |
| | | | | Indoxacarb | 73 | |
| | | | | Fenarimol | 73 | |
| | | | | Acetamiprid | 71 | |
| | Washing + Boiling + Cooking | Samples were washed with tap water for 5 min then boiled for 7 mins and cooked in water for 20 min | | Chlorfenapyr | 91 | |
| | | | | Acetamiprid | 90 | |
| | | | | Fenarimol | 84 | |
| | | | | Indoxacarb | 76 | |
| | Washing + Steaming + Cooking | Samples were washed with tap water for 5 min then steamed using a traditional steam pot for 5 mins and cooked in water for 20 min | | Chlorfenapyr | 94 | |
| | | | | Acetamiprid | 89 | |
| | | | | Fenarimol | 85 | |
| | | | | Indoxacarb | 82 | |
| | Washing + chemical boiling + Cooking | Samples were washed with tap water for 5 min Sodium bicarbonate for 3 min, and cooked for 20 min, immersed in a chemical solution of 250 ppm zinc chloride, 0.5% potassium metabisulphite, 0.1% magnesium oxide, and 0.1% | | Chlorfenapyr | 92 | |
| | | | | Acetamiprid | 89 | |
| | | | | Fenarimol | 86 | |
| | | | | Indoxacarb | 81 | |
| 5 | US + $O_3$ | Samples were cleaned in an ultrasonic cleaner at 25 kHz, at 500 W, and $O_3$ treatment at 75 mg/min, for 60 min at 8 °C | Lettuce | Methamidophos | 79.76 | Fan *et al.* (2015) |
| | | | | Dichlorvos | 68.02 | |
| 6 | | Samples were treated with US at 40 kHz and $O_3$ (3.33 g/min) for 10-15 min | Spinach | Thiamethoxam | 100 | Siddique *et al.* (2021) |
| | | | | Acetamiprid, | 100 | |
| | | | | Imidacloprid | 99.75 | |
| 7 | US + FC | Samples were added to the bath of the ultrasonic cleaner (40 kHz, 600 W) that contained NaOCl solution with an FC concentration of 15 mg/L at 22 °C for 10 min | Tomato | Dimethoate | 93.2 | Yang *et al.* (2022) |
| | | | | Trichlorfon | 86.4 | |
| | | | | Carbofuran | 81.0 | |
| | | | Lettuce | Dimethoate | 86.7 | |
| | | | | Trichlorfon | 79.8 | |
| | | | | Carbofuran | 71.3 | |
| | | | Spinach | Dimethoate | 74.7 | |
| | | | | Trichlorfon | 72.3 | |
| | | | | Carbofuran | 70.2 | |
| | | | Celery | Dimethoate | 88.5 | |
| | | | | Trichlorfon | 82.2 | |
| | | | | Carbofuran | 78.8 | |
| | | | Bean | Dimethoate | 90.4 | |
| | | | | Trichlorfon | 86.1 | |
| | | | | Carbofuran | 80.4 | |
| 8 | US (Bath or Probe) + EC | Samples were treated with electro-sonication processes for 10 min at EC of 1400 mA and US bath at 40 kHz | Tomato | Captan | 94.24 | Cengiz *et al.* (2018) |
| | | 2. EC 800 mA and US Probe 24 kHz | | Thiamethoxam | 69.80 | |
| | | 3. EC 1400 mA and US Probe 24 kHz | | Metalaxyl | 95.06 | |
| 9 | US + VW | Ultrasonic dishwashing for 16 min: VW for 3 min. US washing for 9 min. VW for 4 min | Grape | Abamectin | 100 | Zhou *et al.* (2019) |
| | | | | Tebuconazole | 88.4 | |
| | | | | Thiamethoxam | 85.9 | |
| | | | | Difenoconazole | 82.0 | |
| | | | | Azoxystrobin | 72.1 | |
| 10 | US + Electrolyzed water | AC water and/or AK water | Leafy cabbage | Methamidophos | 33.8 | Lin *et al.* (2006) |
| | | | | Dimethoate | 31.6 | |
| | | | Green pepper | Methamidophos | 17.0 | |
| | | | | Dimethoate | 28.7 | |

US: Ultrasound; FC: Free Chlorine; $O_3$: Ozone. LIEC: Low-intensity electric current, VW: Vortex washing, Chemical solution 250 ppm zinc chloride, 0.5% potassium metabisulphite, 0.1% magnesium oxide, and 0.1% sodium bicarbonate; EC: Low-intensity electrical current; AC: electrolyzed oxidizing; AK: alkaline electrolyzed.

## Challenges and future trends directions in pesticide elimination methods

The removal of pesticides from F & V is a critical aspect of ensuring food safety and consumer confidence. While various methods have shown promise, several challenges persist. Opportunities for future research in pesticide elimination methods from F & V include exploring the effectiveness of combined processing technologies (Zhang *et al.*, 2022). These technologies are more effective than individual technologies in reducing pesticide residues and retaining the quality attributes of F & V (Hsu *et al.*, 2022). Additionally, further investigation is needed into non-thermal processing technologies such as ultrasound, cold plasma, high-pressure processing, and pulsed electric fields, which have shown great potential in eliminating pesticide residues with minimal impact on the quality of F & V (Sellamuthu & Kumar Kaliappan, 2023). Moreover, there is a need to develop eco-friendly alternatives to chemical pesticides and promote integrated pest management strategies. Improved detection and warning systems for pesticide residues are necessary for the safety of farmers and consumers. This requires accurate, rapid, non-destructive, and cost-effective methods for identifying and measuring pesticide residues. Technological innovations such as remote sensing, data analytics, and precision agriculture can facilitate the optimal removal of pesticide residues in various food matrices, such as F & V, considering the complexity of the matrices and the diversity of pesticides (Ssemugabo *et al.*, 2022). Furthermore, the introduction and the implementation of the Industry-4.0 technologies such as big data, deep learning, and AI technologies, can enhance sustainable accurate food risk assessment and predictions (Aït-Kaddour *et al.*, 2024).

Overall, future research should balance the focus between efficacy, produce quality and developing green and pollution-free technologies for pesticide elimination, and finding ways to effectively and minimize pesticide use in the agricultural field (Tang *et al.*, 2023). Furthermore, pesticide removal methods should not compromise the sensory attributes, nutritional quality, or shelf life of F & V with the reduction of environmental footprint (Zhang *et al.*, 2022).

Education and awareness among farmers and consumers about the advantages and risks associated with pesticides are vital, and promoting organic farming practices and consumption can significantly reduce pesticide use. For that, effective communication of pesticide risks to consumers and conducting long-term studies to evaluate the impacts of pesticides on human health are imperative to ensure the safety and well-being of individuals and communities (Sabran & Abas, 2021). Also, educating consumers about the benefits of pesticide-free produce and proper handling practices can help promote the demand for and acceptance of pesticide-free F & V. Before effectively eliminating pesticides, it is important to invest in consumer education initiatives, such as labeling, certification programs, and communication campaigns, to increase awareness and foster consumer confidence in pesticide-free produce (Simoglou & Roditakis, 2022).

Also, pesticide elimination methods must evolve in alignment with upcoming innovations and future trends in pesticide usage, particularly regarding their effectiveness, toxicity, and sustainability, including the adoption of biopesticides.

Exploring the potential of these pesticide elimination technologies, along with assessing their economic feasibility and scalability, can provide opportunities for more efficient and sustainable pesticide use. By considering these factors and implementing appropriate techniques, it is possible to effectively eliminate chemical pesticides from harvested F & V. However, it is important to carefully assess the specific requirements and challenges associated with each technique to ensure their efficacy, efficiency, safety, affordability, and practicality in commercial production, household, and distribution systems.

Compared to previous reviews, which often focused on individual removal techniques or specific types of pesticides, this study provides a broader and more integrated overview by systematically comparing conventional, advanced, and combined methods for pesticide residue removal from fruits and vegetables. One major strength lies in the inclusion of both household and industrial-scale techniques, offering insights that are relevant for consumers, researchers, and the food industry. Furthermore, the review emphasizes the combination of methods, an approach that has been underexplored in earlier literature, and highlights their potential for improved efficiency.

However, this work also has certain limitations in comparison to prior studies. First, while it covers a wide range of methods, it does not provide a detailed mechanistic analysis of each technique. Second, the lack of standardized metrics across the included studies makes direct quantitative comparisons difficult. Finally, the review does not experimentally validate the findings, which may limit the immediate applicability of the conclusions. Nonetheless, by identifying gaps and proposing directions for future research, this study contributes meaningfully to the evolving discourse on food safety and pesticide mitigation.

## Conclusion

In response to the growing demand for fresh produce and the need to ensure food safety while protecting consumer health, various methods have been explored to effectively reduce pesticide residues in fruits and vegetables (F & V). These range from practical household techniques to advanced and combined approaches, each with varying degrees of efficiency and feasibility. Household methods, including washing, peeling, and soaking with additives such as vinegar or sodium bicarbonate, offer accessible and cost-effective solutions. Peeling remains the most efficient for non-systemic pesticides, achieving up to 100% removal, while washing under running water typically reaches up to 90%. Soaking in sodium bicarbonate has shown superior results compared to acetic acid, particularly on leafy vegetables, due to its ability to induce alkaline hydrolysis. Advanced methods such as ozonation, cold plasma, and ultrasound have demonstrated higher removal efficiencies, often exceeding 90%, with ultrasound being especially effective for soft, porous produce like lettuce. Furthermore, combining techniques-such as ultrasound with ozonation or electrolyzed water-can enhance efficacy, achieving up to 99% residue removal in some cases.

This review highlights that no single method is universally effective; instead, the success of each technique depends on multiple variables, including pesticide type, produce characteristics, and treatment conditions. While advanced methods offer higher removal rates, their accessibility and cost limit widespread application. Despite the progress made, key gaps remain. Few studies assess the impact of these methods on nutritional quality, sensory attributes, or the formation of toxic metabolites. Moreover, the absence of standardized protocols across studies complicates cross-comparison. Future research should focus on understanding removal mechanisms, improving detection technologies, and developing scalable, safe, and consumer-friendly decontamination strategies. This integrated approach is essential to support sustainable agriculture and food safety in the context of increasing pesticide use.

## Acknowledgement

The authors declare that they have no funding support for this study.

## Author contributions

**Zoubeida Meghlaoui:** Data collection, Presenting the research idea and study design, Writing the draft of the manuscript, Data analysis and interpretation, Revising and editing the manuscript, Supervising the study, Approval of the final version; **Hocine Remini:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation, Revising and editing the manuscript; **Yasmine Remini-Sahraoui:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation, Revising and editing the manuscript; **Mohamed Khalil Mellal:** Data analysis, Data collection, Writing the draft of the manuscript, Data analysis and interpretation, Revising and editing the manuscript, Approval of the final version; **Sofiane Boudalia:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation, Approval of the final version; **Yasmine Brahimi:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Samira Negrichi:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Ayoub Allam:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Lamia Medouni-Haroune:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Lynda Messaoudene:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Amina Abbou:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Amokrane Mahdeb:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Nassim Brahimi:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Meriem Amrane-Abider:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Zahia Brara:** Data collection, Writing the draft of the manuscript, Data analysis and interpretation; **Khodir Madani**: Presenting the research idea and study design.

## Conflict of interest

There is no conflict of interest based on the writers.

## Reference

Bonnechère, A., B, T., Hanot, V., Bragard, C., & Loco, J. van. (2012). Effect of household and industrial processing on the levels of pesticide residues and degradation products in melons. *Food Additives & Contaminants: Part A*, *29*(7), 1058-1066. https://doi.org/10.1080/19440049.2012.672339

Ahn-Jarvis, J. H., Parihar, A., & Doseff, A. I. (2019). Dietary Flavonoids for Immunoregulation and Cancer : Food Design for Targeting Disease. *Antioxidants*, *8*(7). https://doi.org/10.3390/antiox8070202

Aiassa, D. E., Mañas, F. J., Gentile, N. E., Bosch, B., Salinero, M. C., & Gorla, N. B. M. (2019). Evaluation of genetic damage in pesticides applicators from the province of Córdoba, Argentina. *Environmental Science and Pollution Research*, *26*(20), 20981-20988. https://doi.org/10.1007/s11356-019-05344-2

Aidoo, O. F., Osei-Owusu, J., Chia, S. Y., Dofuor, A. K., Antwi-Agyakwa, A. K., Okyere, H., Gyan, M., Edusei, G., Ninsin, K. D., Duker, R. Q., Siddiqui, S. A., & Borgemeister, C. (2023). Remediation of pesticide residues using ozone: A comprehensive overview. *Science of The Total Environment*, *894*, 164933. https://doi.org/10.1016/j.scitotenv.2023.164933

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: Their benefits and hazards. *Interdisciplinary Toxicology*, *2*(1), 1-12. https://doi.org/doi:10.2478/v10102-009-0001-7

Al-Taher, F., Chen, Y., Wylie, P., & Cappozzo, J. (2013). Reduction of Pesticide Residues in Tomatoes and Other Produce. *Journal of Food Protection*, *76*(3), 510-515. https://doi.org/10.4315/0362-028X.JFP-12-240

An, J. M., Chang, S. Y., Lim, H. J., Park, J. O., Kim, I. S., Hwang, H. R., Park, D. H., Kim, I. R., & Kang, M. G. (2020*). Reduction of Pesticide Residues in Korean melon after Washing and Peeling. Nong'yag Gwahag Hoeji, 24(1), 51–62.* Https://doi.org/10.7585/kjps.2020.24.1.51.

Anbarasan, R., Jaspin, S., Bhavadharini, B., Pare, A., Pandiselvam, R., & Mahendran, R. (2022b). Chlorpyrifos pesticide reduction in soybean using cold plasma and ozone treatments. *LWT*, *159*, 113193. https://doi.org/10.1016/j.lwt.2022.113193

Arowolo, O. K., Gbaye, O. A., & Aborisade, A. T. (2022). Effect of household processing methods on insecticide residues in two tomato cultivars from the market in Ondo State, Nigeria. *Toxicology and Environmental Health Sciences*, *14*(4), 371-378. https://doi.org/10.1007/s13530-022-00151-8

Aune, D., Giovannucci, E., Boffetta, P., Fadnes, L. T., Keum, N., Norat, T., Greenwood, D. C., Riboli, E., Vatten, L. J., & Tonstad, S. (2017). Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality—A systematic review and dose-response meta-analysis of prospective studies. *International Journal of Epidemiology*, *46*(3), 1029-1056. https://doi.org/10.1093/ije/dyw319

Azam, S. M. R., Ma, H., Xu, B., Devi, S., Stanley, S. L., Siddique, M. A. B., Mujumdar, A. S., & Zhu, J. (2021). Multi-frequency multi-mode ultrasound treatment for removing pesticides from lettuce (Lactuca sativa L.) and effects on product quality. *LWT*, *143*, 111147. https://doi.org/10.1016/j.lwt.2021.111147

Carnesecchi, E., Mostrag, A., Ciacci, A., Roncaglioni, A., Tarkhov, A., Gibin, D., & et al. (2023). *OpenFoodTox: EFSA's chemical hazards database, Zenodo*

Cengiz, M. F., Başlar, M., Basançelebi, O., & Kılıçlı, M. (2018). Reduction of pesticide residues from tomatoes by low intensity electrical current and ultrasound applications. *Food Chemistry*, *267*, 60-66. https://doi.org/10.1016/j.foodchem.2017.08.031

Chung, S. W. (2018). How effective are common household preparations on removing pesticide residues from fruit and vegetables? A review. *Journal of the Science of Food and Agriculture*, *98*(8), 2857-2870. https://doi.org/10.1002/jsfa.8821

Cong, L., Huang, M., Zhang, J., & Yan, W. (2021). Effect of dielectric barrier discharge plasma on the degradation of malathion and chlorpyrifos on lettuce. *Journal of the Science of Food and Agriculture*, *101*(2), 424-432. https://doi.org/10.1002/jsfa.10651

Díaz-López, M., Siles, J. A., Ros, C., Bastida, F., & Nicolás, E. (2022). The effects of ozone treatments on the agro-physiological parameters of tomato plants and the soil microbial community. *Science of The Total Environment*, *812*, 151429. https://doi.org/10.1016/j.scitotenv.2021.151429

El-Sheikh, E.-S. A., Ramadan, M. M., El-Sobki, A. E., Shalaby, A. A., McCoy, M. R., Hamed, I. A., Ashour, M.-B., & Hammock, B. D. (2022). Pesticide Residues in Vegetables and Fruits from Farmer Markets and Associated Dietary Risks. *Molecules*, *27*(22). https://doi.org/10.3390/molecules27228072

Fan, X.-D., Zhang, W.-L., Xiao, H.-Y., Qiu, T.-Q., & Jiang, J.-G. (2015). Effects of ultrasound combined with ozone on the degradation of organophosphorus pesticide residues on lettuce. *RSC Adv.*, *5*(57), 45622-45630. https://doi.org/10.1039/C5RA03024B

FAO. (2021). *Production. Crops and livestock products. Food and Agriculture Organization of the United Nations (FAO).* Http://www.fao.org/faostat/en/#data.(s.d.)

Forkuoh, F., Boadi, N. O., Borquaye, L. S., & Afful, S. (2018). Risk Of Human Dietary Exposure To Organochlorine Pesticide Residues In Fruits From Ghana. *Scientific Reports*, *8*(1), 16686. https://doi.org/10.1038/s41598-018-35205-w

Gao, Y., Yang, A., Zurbau, A., & Gucciardi, E. (2023). The Effect of Food is Medicine Interventions on Diabetes-related Health Outcomes Among Low-income and Food-insecure Individuals: A Systematic Review and Meta-analysis. *Canadian Journal of Diabetes*, *47*(2), 143-152. https://doi.org/10.1016/j.jcjd.2022.11.001

Głąbska, D., Guzek, D., Groele, B., & Gutkowska, K. (2020). Fruit and Vegetable Intake and Mental Health in Adults : A Systematic Review. *Nutrients*, *12*(1). https://doi.org/10.3390/nu12010115

Hanafi, A., Elsheshetawy, H. E., & Faied, S. F. (2016). Reduction of pesticides residues on okra fruits by different processing treatments. *Journal für Verbraucherschutz und Lebensmittelsicherheit*, *11*(4), 337-343. https://doi.org/10.1007/s00003-016-1054-0

Hao, J., Wuyundalai, Liu, H., Chen, T., Zhou, Y., Su, Y.-C., & Li, L. (2011). Reduction of Pesticide Residues on Fresh Vegetables with Electrolyzed Water Treatment. *Journal of Food Science*, *76*(4), C520-C524. https://doi.org/10.1111/j.1750-3841.2011.02154.x

Heshmati, A., & Nazemi, F. (2017). Dichlorvos (DDVP) residue removal from tomato by washing with tap and ozone water, a commercial detergent solution and ultrasonic cleaner. *Food science and technology*, *38*(3), 441-446.

Huan, Z., Xu, Z., Jiang, W., Chen, Z., & Luo, J. (2015a). Effect of Chinese traditional cooking on eight pesticides residue during cowpea processing. *Food Chemistry*, *170*, 118-122. https://doi.org/10.1016/j.foodchem.2014.08.052

Iram, A., Wang, X., & Demirci, A. (2021). Electrolyzed Oxidizing Water and Its Applications as Sanitation and Cleaning Agent. *Food Engineering Reviews*, *13*(2), 411-427. https://doi.org/10.1007/s12393-021-09278-9

Iizuka, T., & Shimizu. A. (2014). Removal of pesticide residue from Brussels sprouts by . *Innovative Food Science & Emerging Technologies 22,* 70-75.

Kalyabina, V. P., Esimbekova, E. N., Kopylova, K. V., & Kratasyuk, V. A. (2021). Pesticides : Formulants, distribution pathways and effects on human health – a review. *Toxicology Reports*, *8*, 1179-1192. https://doi.org/10.1016/j.toxrep.2021.06.004

Liang, Y., Wang, W., Shen, Y., Liu, Y., & Liu, X. J. (2012). Effects of home preparation on organophosphorus pesticide residues in raw cucumber. *Food Chemistry*, *133*(3), 636-640. https://doi.org/10.1016/j.foodchem.2012.01.016

Lin, C.-S., Tsai, P.-J., Wu, C., Yeh, J.-Y., & Saalia, F. K. (2006). Evaluation of electrolysed water as an agent for reducing methamidophos and dimethoate concentrations in vegetables. *International Journal of Food Science & Technology*, *41*(9), 1099-1104. https://doi.org/10.1111/j.1365-2621.2006.01192.x

Liu, Y., Wang, J., Zhu, X., Liu, Y., Cheng, M., Xing, W., Wan, Y., Li, N., Yang, L., & Song, P. (2021a). Effects of electrolyzed water treatment on pesticide removal and texture quality in fresh-cut cabbage, broccoli, and color pepper. *Food Chemistry*, *353*, 129408. https://doi.org/10.1016/j.foodchem.2021.129408

López-Fernández, O., Rial-Otero, R., & Simal-Gándara, J. (2013). Factors governing the removal of mancozeb residues from lettuces with washing solutions. *Food Control*, *34*(2), 530-538. https://doi.org/10.1016/j.foodcont.2013.05.022

Lozowicka, B., Jankowska, M., Hrynko, I., & Kaczynski, P. (2015). Removal of 16 pesticide residues from strawberries by washing with tap and ozone water, ultrasonic cleaning and boiling. *Environmental Monitoring and Assessment*, *188*(1), 51. https://doi.org/10.1007/s10661-015-4850-6

Majumder, S., Pandey, J., Bhadwaj, D. R., Pandey, K. K., & Behera, T. K. (2023). Effectiveness of common household methods for removal of deltamethrin from vegetables. *Vegetable Science*, *50*(2), 383-388. https://doi.org/10.61180/vegsci.2023.v50.i2.18

Mao, L., Mhaske, P., Zing, X., Kasapis, S., Majzoobi, M., & Farahnaky, A. (2021). Cold plasma : Microbial inactivation and effects on quality attributes of fresh and minimally processed fruits and Ready-To-Eat vegetables. *Trends in Food Science & Technology*, *116*, 146-175. https://doi.org/10.1016/j.tifs.2021.07.002

Mebdoua, S. (2018). Pesticide Residues in Fruits and Vegetables. In J.-M. Mérillon & K. G. Ramawat (Éds.), *Bioactive Molecules in Food* (p. 1-39). Springer International Publishing. https://doi.org/10.1007/978-3-319-54528-8_76-1

Megawati, Sulaiman, M. I., & Zakaria, S. (2022). *Effect of planting season on the residue of organophosphate in chili (Capsicum annuum L.).*

Misra, N. N., Pankaj, S. K., Walsh, T., O'Regan, F., Bourke, P., & Cullen, P. J. (2014). In-package nonthermal plasma degradation of pesticides on fresh produce. *Journal of Hazardous Materials*, *271*, 33-40. https://doi.org/10.1016/j.jhazmat.2014.02.005

Naman, M., Masoodi, F. A., Wani, S. M., & Ahad, T. (2022). Changes in concentration of pesticide residues in fruits and vegetables during household processing. *Toxicology Reports*, *9*, 1419-1425. https://doi.org/10.1016/j.toxrep.2022.06.013

Olisah, C., & Adams, J. B. (2020). Systematic mapping of organophosphate contaminant (OPC) research trends between 1990 and 2018. *Environmental Geochemistry and Health*, *42*(11), 3481-3505. https://doi.org/10.1007/s10653-020-00594-3

Patist, A., & Bates, D. (2008). Ultrasonic innovations in the food industry : From the laboratory to commercial production. *Innovative Food Science & Emerging Technologies*, *9*(2), 147-154. https://doi.org/10.1016/j.ifset.2007.07.004

Phopin, K., Wanwimolruk, S., Norkaew, C., Buddhaprom, J., & Isarankura-Na-Ayudhya, C. (2022). Boiling, Blanching, and Stir-Frying Markedly Reduce Pesticide Residues in Vegetables. *Foods*, *11*(10). https://doi.org/10.3390/foods11101463

Qi, H., Huang, Q., & Hung, Y.-C. (2018). Effectiveness of electrolyzed oxidizing water treatment in removing pesticide residues and its effect on produce quality. *Food Chemistry*, *239*, 561-568. https://doi.org/10.1016/j.foodchem.2017.06.144

Radwan, M. A., Abu-Elamayem, M. M., Shiboob, M. H., & Abdel-Aal, A. (2005). Residual behaviour of profenofos on some field-grown vegetables and its removal using various washing solutions and household processing. *Food and Chemical Toxicology*, *43*(4), 553-557. https://doi.org/10.1016/j.fct.2004.12.009

Randhawa, M. A., Anjum, F. M., Ahmed, A., & Randhawa, M. S. (2007). Field incurred chlorpyrifos and 3,5,6-trichloro-2-pyridinol residues in fresh and processed vegetables. *Food Chemistry*, *103*(3), 1016-1023. https://doi.org/10.1016/j.foodchem.2006.10.001

Sánchez, M.-T., Haba, M. J. D. la, Benítez-López, M., Fernández-Novales, J., Garrido-Varo, A., & Pérez-Marín, D. (2012). Non-destructive characterization and quality control of intact strawberries based on NIR spectral data. *Journal of Food Engineering*, *110*(1), 102-108. https://doi.org/10.1016/j.jfoodeng.2011.12.003

Sharma, A., Shukla, A., Attri, K., Kumar, M., Kumar, P., Suttee, A., Singh, G., Barnwal, R. P., & Singla, N. (2020). Global trends in pesticides : A looming threat and viable alternatives. *Ecotoxicology and Environmental Safety*, *201*, 110812. https://doi.org/10.1016/j.ecoenv.2020.110812

Sheikh, S. A., Nizamani, S. M., Jamali, A. A., Panhwar, A. A., Channa, M. J., & Mirani, B. N. (2012). Removal of Pesticide Residues from Okra Vegetable through Traditional Processing. *Journal of Basic &amp; Applied Sciences*, *8*(1), 79-84. https://doi.org/10.6000/1927-5129.2012.08.01.23

Siddique, Z., Malik, A. U., Asi, M. R., Anwar, R., & Inam Ur Raheem, M. (2021). Sonolytic-ozonation technology for sanitizing microbial contaminants and pesticide residues from spinach (Spinacia oleracea L.) leaves, at household level. *Environmental Science and Pollution Research*, *28*(38), 52913-52924. https://doi.org/10.1007/s11356-021-14203-y

Singh, S., Solanki, V., Bardhan, K., Kansara, R., Vyas, T. K., Gandhi, K., Dhakan, D., Ali, H. M., & Siddiqui, M. H. (2022). Evaluation of Ozonation Technique for Pesticide Residue Removal in Okra and Green Chili Using GC-ECD and LC-MS/MS. *Plants*, *11*(23). https://doi.org/10.3390/plants11233202

Soria, A. C., & Villamiel, M. (2010). Effect of ultrasound on the technological properties and bioactivity of food : A review. *Trends in Food Science & Technology*, *21*(7), 323-331. https://doi.org/10.1016/j.tifs.2010.04.003

Statista. (2023). *Global pesticide market report.* New York: Statista Inc.; 2023. Https://www.statista.com/statistics/1263077/global-pesticide-agricultural-use/.(s.d.)

Strassemeyer, J., Daehmlow, D., Dominic, A. R., Lorenz, S., & Golla, B. (2017). SYNOPS-WEB, an online tool for environmental risk assessment to evaluate pesticide strategies on field level. *Crop Protection*, *97*, 28-44. https://doi.org/10.1016/j.cropro.2016.11.036

Tudi, M., Li, H., Li, H., Wang, L., Lyu, J., Yang, L., Tong, S., Yu, Q. J., Ruan, H. D., Atabila, A., Phung, D. T., Sadler, R., & Connell, D. (2022). Exposure Routes and Health Risks Associated with Pesticide Application. *Toxics*, *10*(6). https://doi.org/10.3390/toxics10060335

Wang, D., Du, X., & He, L. (2022). Investigation of the Impact of a Pesticide Adjuvant on Dimethoate Persistence, Penetration, and Stability on Apples

Using Surface-Enhanced Raman Spectroscopy. *ACS Agricultural Science & Technology*, *2*(4), 788-795. https://doi.org/10.1021/acsagscitech.2c00092

Wang, Z., Huang, J., Chen, J., & Li, F. (2013). Effectiveness of dishwashing liquids in removing chlorothalonil and chlorpyrifos residues from cherry tomatoes. *Chemosphere*, *92*(8), 1022-1028. https://doi.org/10.1016/j.chemosphere.2013.03.039

Yang, L., Zhou, J., & Feng, Y. (2022). Removal of pesticide residues from fresh vegetables by the coupled free chlorine/ultrasound process. *Ultrasonics Sonochemistry*, *82*, 105891. https://doi.org/10.1016/j.ultsonch.2021.105891

Yang, Z., Zhang, S., Wang, F., Dong, B., & Cai, M. (2025). Occurrence and health risk assessment of organic amine pesticides in drinking water of the Yangtze River delta urban agglomeration. *Journal of Environmental Sciences (China)*, *152*, 99-110. Scopus. https://doi.org/10.1016/j.jes.2024.04.034

Zhang, A.-A., Sutar, P. P., Bian, Q., Fang, X.-M., Ni, J.-B., & Xiao, H.-W. (2022). Pesticide residue elimination for fruits and vegetables : The mechanisms, applications, and future trends of thermal and non-thermal technologies. *Journal of Future Foods*, *2*(3), 223-240. https://doi.org/10.1016/j.jfutfo.2022.06.004

Zhang, B. H., Xu, X., Lu, H., Wang, L., & Yang, Q. (2021). Removal of phoxim, chlorothalonil and Cr3+ from vegetable using bubble flow. *Journal of Food Engineering*, *291*, 110217. https://doi.org/10.1016/j.jfoodeng.2020.110217

Zhou, Q., Bian, Y., Peng, Q., Liu, F., Wang, W., & Chen, F. (2019). The effects and mechanism of using ultrasonic dishwasher to remove five pesticides from rape and grape. *Food Chemistry*, *298*, 125007. https://doi.org/10.1016/j.foodchem.2019.12500

Zhu, Y., Zhang, T., Xu, D., Wang, S., Yuan, Y., He, S., & Cao, Y. (2019). The removal of pesticide residues from pakchoi (Brassica rape L. ssp. Chinensis) by ultrasonic treatment. *Food Control*, *95*, 176-180. https://doi.org/10.1016/j.foodcont.2018.07