

Evaluation of Critical Pesticide Residues in Local and Imported Food Samples in Bahrain

Amjad Ghanem Mohamed*^{ID}, Afaf Merza Mohamed, Heba Mohamed Abdulredha, Masooma Abbas Alghawas, Eman Ali Jassim, Fatima S. Hashem Ali

Public Health Directorate, Ministry of Health, Manama, Kingdom of Bahrain
Email: *Azaed@Health.gov.bh

How to cite this paper: Mohamed, A.G., Mohamed, A.M., Abdulredha, H.M., Alghawas, M.A., Jassim, E.A. and Ali, F.S.H. (2025) Evaluation of Critical Pesticide Residues in Local and Imported Food Samples in Bahrain. *Health*, 17, 783-799.
<https://doi.org/10.4236/health.2025.176050>

Received: April 20, 2025

Accepted: June 24, 2025

Published: June 27, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

This study aimed to assess the levels of pesticide residues in different food commodities in Bahrain and to use it as a reference for future monitoring. A retrospective review of all the foods tested in the public health laboratory between 2015 and 2019 was conducted. The 522 commodities included vegetables from local farms, imported fruit and vegetables, imported spices, locally manufactured spices, and other imported food commodities. Seventy-six types of pesticides were detected, of which 76.3% were organophosphates and 23.7% were organochlorines. Pesticide residues were detected in 34% of the samples, 31% of the detected samples were from local food commodities, while 69% were imported. Among the positive samples, 19% were vegetables and fruits, 59% were spices, and 22% were others. Only 9% of the samples detected did not meet national standards. The highest pesticide residues were Myclobutanil (26%) and Azoxystrobin and Myclobutanil (8%). There is an increased need to routinely test and monitor pesticide residues in local crops in collaboration with the concerned authorities.

Keywords

Bahrain, Pesticides, Detection, Food Safety, QuEChERS, Residues, Chromatography, Organochlorine, Organophosphate

1. Introduction

Pesticides have been an important component of worldwide agriculture systems since the last century, allowing for a noticeable increase in crop yields and food production [1]. Pesticides are essential in protecting plants as chemical substances that help keep plants safe from many terrible diseases [2]. Pesticides are the only toxic substances released intentionally into the environment to kill unwanted liv-

ing organisms. This includes substances that kill weeds (herbicides), insects (insecticides), fungus (fungicides), rodents (rodenticides), and others. In 1960, organochlorine insecticides, which successfully controlled malaria and typhus, were banned in many countries. Many insecticides, such as organophosphates, carbamates, pyrethroids, and other herbicides and fungicides, were introduced between the 1960s and 1980s and contributed widely to pest control and agricultural output. Using toxic pesticides to manage pest problems has become common worldwide [2] [3]. Pesticides are potentially harmful to humans and can have both acute and chronic health effects, depending on how a person is exposed [3] [4]. Since most fruits and vegetables are eaten raw, they are recognized as food containing higher pesticide residue levels [5].

Many countries have banned pesticides such as Dichlorodiphenyltrichloroethane (DDT) and limited the dosage of other pesticides that can adversely affect human health. However, these pesticides are still in use by some countries. This has been documented in many scientific studies [5]-[7]. The Kingdom of Bahrain imports many foodstuffs from different countries that may use these pesticides. On the other hand, because of the climatic conditions and the fact that Bahrain falls under the water poverty belt, the area of arable land in Bahrain is 6.4 thousand hectares, or 9% of the total area. Accordingly, the self-sufficiency rate in vegetables was estimated at only 19% [8]. Therefore, the Kingdom of Bahrain imports most of its fruits and vegetables [8] [9].

The Kingdom of Bahrain regulates pesticides through a multifaceted regulatory framework to manage and monitor pesticide use. The Supreme Council for Environment and the Ministry of Municipalities Affairs and Agriculture oversee licensing, importation, and safe use [10] [11]. Monitoring includes pesticide residue testing by accredited labs like SGS, following international Good Laboratory Practices [12]. The country also aligns with global conventions such as the Stockholm and Basel agreements [13] [14]. While the framework is robust, there is room for improvement in inter-agency coordination, transparency, and national chemical inventory creation [14].

To ensure the safety and quality of Bahrain's food supply, the public health directorate has continuously monitored pesticides and other toxic residues in foods and water. Public health inspectors routinely collect food samples from commodities arriving in Bahrain through Bahrain International Airport, King Fahad Causeway, and Mina Khalifa. These samples include fresh, frozen, canned vegetables and fruits, spices, cereals, and other types of food and local products from different food factories and farms. All food and water samples are collected and sent to the public health laboratory (PHL) for pesticide residue testing. To ensure compliance with regulatory standards, food and water are tested for 402 different types of pesticides and chemical and toxicological analysis tests. Scientific papers or literature in Bahrain insufficiently report the presence of pesticide residues in locally produced or imported food. This study aims to assess the levels of pesticide residues in different food commodities in Bahrain and use the results as a refer-

ence for future monitoring.

2. Materials and Methods

A retrospective review of all the food commodities tested in the public health laboratory between 2015 and 2019 was conducted. The sampling strategy was non-probability sampling in particular purposive sampling to enable a representative sample to be obtained from a lot, for analysis to determine compliance with GCC/Codex Maximum Residue Limits (MRLs) for pesticides, in which the samples chosen for pesticide analysis included locally grown produce, imported fresh produce, or processed food that contained ingredients from plant origin. This type of targeted sampling is essential to acquire baseline data regarding the concentration and types of pesticides available in food consumed in Bahrain. The commodities for this study included vegetables from local farms, imported fruit and vegetables, imported spices, locally manufactured spices, and other imported food commodities. Five hundred twenty-two samples were analyzed for pesticide residues against regional and internationally accepted residue limits. The reviewed data included the source of commodities, local or imported, and the types of pesticides detected.

2.1. Sample Collection

2.1.1. Sampling Strategy for Pesticide Residue Analysis in Food

Sampling activities were undertaken by public health inspectors from the Food Control Section—Ministry of Health, with collection sites strategically selected to encompass both domestic and imported food sources. Locally produced samples were obtained from the Central Market, representing foods commonly available to consumers. Imported food samples were collected at Bahrain's principal entry points, including Bahrain International Airport, King Fahad Causeway, and Mina Khalifa Port. This sampling approach ensured comprehensive coverage of the food supply chain, thereby facilitating a focused assessment of pesticide exposure risks and supporting the formulation of evidence-based food safety policies in the Kingdom of Bahrain [15].

2.1.2. Collection and Preparation of Laboratory Samples

Based on the sample type, the number of primary samples collected from each lot was determined per the guidelines specified in CAC/GL 33. Each primary sample was randomly collected from a distinct location within the lot, as practicably feasible. The volume of each sample was sufficient to yield the required laboratory sample(s) [16].

Each primary sample was initially treated as a separate bulk sample. Where practicable, all primary samples from a given lot were combined and thoroughly homogenized to produce a composite bulk sample. When the bulk sample exceeded the quantity needed for laboratory analysis, a representative laboratory sample was obtained through appropriate size reduction techniques, such as quartering or using sampling devices. Notably, whole units of perishable commodities

(e.g., fresh plant products or entire eggs) were not altered (cut or broken) to preserve sample integrity.

Detailed records were maintained for each sampling event. The information documented included: the nature and origin of the lot; identification of the owner, supplier, or carrier; date and location of sampling; and any deviations from standard sampling procedures. This ensured traceability and compliance with regulatory guidelines. Each sample was labeled at the time of collection with a unique identifier including the date, time, location, and product description. A detailed sampling form accompanied each sample, recording the sample source (local or imported), collection point (e.g., central market or airport), inspector's name and signature, and any observed conditions affecting sample quality. Analytical requirements collected sample quantities, typically 500 g for fresh produce or 2 - 5 units for packaged items, ensuring representativeness. Samples were securely sealed and transported to the laboratory as promptly as possible. Measures were taken to prevent deterioration during transit—fresh samples were kept cool, and frozen samples remained frozen. A sample collection form was used to maintain full chain-of-custody from collection through analysis, ensuring accountability and traceability.

2.2. Chemical Analytical Method

Reference standards for organochlorine pesticides including α -hexachlorocyclohexane, beta-hexachlorocyclohexane, gamma-benzenehexachloride, heptachlor, aldrin, heptachlor endo-epoxide, 2,4-dichlorodiphenyldichloroethylene, apha-endosulfan, cis-chlordane, 2,4-dichlorodiphenyldichloroethane, 4,4-dichlorodiphenyldichloroethylene, dieldrin, 2,4-dichlorodiphenyltrichloroethane, 4,4-DDD, beta-endosulfan, endrin aldehyde, endrin, 4,4-dichlorodiphenyltrichloroethane, endosulfan sulfate, endrin ketone, were purchased from Fluka, Supelco, Central Insecticides Laboratory (CIL) and Sigma-Aldrich with certified purity ranging from 95% to 99.8%. The carbamate and organophosphorus standards (#1, #2, #3, #4, #5, #6, #7, #8, #9, #10) 100 $\mu\text{g/mL}$ -Acetonitrile were used from the Restek company.

2.3. Standard Preparation

Pesticide standards for organochlorine pesticides shall be > 99% purity; for standards of <99%, apply appropriate correction factors to measured weights. Rinse all volumetric flasks and pipettes with hexane. Prepare all standards in ethyl acetate. In the case of solids, weigh a known standard quantity in a beaker, transfer quantitatively with ethyl acetate, and make up to volume. In case of semisolids and liquids, add material to the tared volumetric flask, immediately stopper, and reweigh the flask.

a) Stock solution of standards (1000 mg/L): Weigh accurately 0.01 g of standard (apply correction for purity for standards with purity <99.0%) and make up to volume in a 10 mL volumetric flask with ethyl acetate.

b) Intermediate standard I (100.00 mg/L): Pipette 1 mL of stock solution into a 10 mL volumetric flask and make up to volume with ethyl acetate. For intermediate standard II (10.00 mg/L): Pipette 1 mL of intermediate standard I into a 10 mL volumetric flask and make up to volume with ethyl acetate. For intermediate standard III (1.0 mg/L)—(for OCL only) Pipette 1 mL of intermediate standard II into a 10 mL volumetric flask and make up to volume with ethyl acetate.

c) Working standard [OCL (0.10 mg/L)]: Pipette 1 mL of intermediate standard III (5.4) for OCL into a 10 mL volumetric flask and make up to volume with ethyl acetate.

For carbamates and organophosphorus pesticides, multi-residue pesticide kit standards from the Restek company contain 204 compounds of interest, covering many LC-determined pesticides listed by government agencies. The kit contains 10 standard ampoules, each 1 mL volume containing different pesticide compounds. The concentration of each standard is 100 µg/mL.

a) Stock solution of 10 mix pesticides standards (100 mg/L).

b) Intermediate standard (10 ppm): Take 100 µl from each Restek mix standard (stock standards) in a 1 mL vial.

c) Working standards from the intermediate standard prepare five different standards levels for the method calibration (500 ppb, 200 ppb, 100 ppb, 50 ppb, and 10 ppb) and dilute with (10% ACN: 10% Methanol: 80% Water).

2.4. Gas Chromatography Tandem Mass Spectrometry (GC-MS/MS) Analysis

All the organic solvents used were of high-performance liquid chromatography (HPLC) grade. This includes acetonitrile, toluene, methanol, and formic acid. Graphite carbon black (GCB) was used. An Agilent Technologies 7890B gas chromatography system equipped with a mass selective detector and an Agilent column (30 m long, 250 µm internal diameter, and 0.25 µm film thickness) was used for analysis. Sample injection was performed in the split-less mode, with an injector temperature of 250 °C. The temperature of the oven was programmed from an initial value of 80 °C for 2 min, ramped to 160 °C at 20 °C·min⁻¹ for 7 min, and to 270 °C at 10 °C·min⁻¹ for 28 min. Helium was a carrier gas with a constant flow rate of 0.75 mL·min⁻¹. Electron ionization was used at -70 eV in selective ion monitoring (SIM) and full-scan modes between 50 m/z and 500 m/z for detecting different analytes. The following organochlorine pesticides and their metabolites were analyzed with GC-MS/MS: alpha-HCH, beta-HCH, gamma-BHC, heptachlor, aldrine, heptachlor epoxide, 2,4 DDE, alpha-endosulfan, cis-chlordane, 2,4 DDD, 4,4-DDE, dieldrin, 2,4 DDT, 4,4 DDD, beta endosulfan, endrin aldehyde, endrin, 4,4 DDT, endosulfan sulfate, endrin ketone, and the other pesticides were analyzed with LC-MS/MS.

2.5. Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) Analysis

LC-MS/MS analysis was performed using a liquid chromatography (Waters AC-

QUITY UPLC System) coupled with a triple quadrupole mass detector (Xevo), and a Waters ACQUITY UPLC BEH C-18 analytical column of 2.1×100 mm and $1.7 \mu\text{m}$ particle size. The column temperature was 40°C and sample vial was kept at 4°C , the MS system was (Waters ACQUITY TQ Detector), the ionization mode ESI positive polarity, the capillary voltage was 1 KV, the desolvation gas was nitrogen (800 L/Hr , 400°C), the cone gas Nitrogen (5 L/Hr), the source temp 120°C , Acquisition (Multiple Reaction Monitoring MRM) and the collision gas Argon at $3.5 \times 10 \text{ mBar}$. 98:2 water: methanol + 0.1% formic acid (mobile phase A), and methanol containing 0.1% formic acid (mobile phase B) were used for the gradient program, which started with 95% A for 7 min and was linearly increased to 100% B over 3 min. The column temperature was kept at 35°C , and the injection volume was $20 \mu\text{L}$ with a constant flow rate of 0.450 mL/min .

2.6. Sample Preparation

Samples were received at PHL and placed in labeled, sterile polythene bags in an icebox to avoid contamination and deterioration. A representative portion of the samples was chopped into small pieces and blended using a food processor type of Stephan food processing machinery. In the case of fruits and vegetables, cryogenic milling (using dry ice) was done to increase homogeneity and thus reduce sub-sampling variation and the size of the sample particles. Samples were coarsely cut into small pieces (3×3) with a knife and then frozen (-18°C overnight). The homogenized samples were analyzed immediately or stored at 4°C and analyzed within 24 hours. The homogenized food samples were dissolved in organic solvent using QuEChERS sample extract tubes from Agilent. QuEChERS is a simple sample preparation technique suitable for multi-residue pesticide analysis in different types of food and agricultural products. Once the sample was mixed, the pesticide residues were partitioned into the organic solvent and subjected to further clean-up. The ready sample was filtered, collected, diluted, and injected into the GC-MS/MS and LC-MS/MS systems.

2.7. Solid-Phase Extraction

A $10 \text{ g} \pm 0.1 \text{ g}$ of homogenized sample was weighted in a 50 mL QuEChERS extract tube then 10 ml of acetonitrile and one QuEChER pouch containing 6 g magnesium sulfate and 1.5 g sodium acetate was added to the tube; shaken vigorously by hand for one minute and centrifuged for 5 min at 4000 RPM at 4°C . Then 6ml of the acetonitrile extract was transferred into the 15 mL dispersive SPE tube containing 400.1 mg PSA and 1199.9 mg of magnesium sulfate; shaken vigorously by hand for 1 minute and centrifuged at 5 min and 4000 RPM at 4°C then 1 mL of the extract was filtered through $0.45\mu\text{m}$ PTFE membrane filter and transfer to a 2 mL autosampler vial before GC-MS/MS or LC-MS/MS analysis.

2.8. Result Evaluation

The evaluation of samples and the determination of maximum residue limits

(MRLs) for pesticide residues rely on Gulf standards, Codex Alimentarius, or European regulations, depending on the type and nature of the product. Due to variations in pesticide types, product characteristics, and permissible limits across different standards, it is not easy to list all MRLs for all pesticides detected in all samples. For example, the maximum residue limits for pesticides in food samples can vary significantly: European regulations may impose stricter limits or even bans on certain pesticides due to health concerns, Codex Alimentarius establishes internationally recognized MRLs based on food safety assessments, and Gulf standards determine MRLs based on regional studies and alignment with global regulations. In addition, we can see this difference in **Table 1**, which compares two types of pesticides and their respective MRLs, which vary depending on the product type.

Table 1. Comparison of two types of pesticides and their respective MRLs.

Pesticide	Rice	Wheat	Teas	Herbs
Endrin (F)	0.01 mg/Kg	0.01 mg/Kg	0.01 mg/Kg	0.1 mg/Kg
Azoxystrobin	5 mg/Kg	0.5 mg/Kg	0.05 mg/Kg	60 mComparisong/Kg

2.9. Data Analysis

Data cleaning and coding were performed using Python, and data analysis was performed using the Statistical Package for the Social Sciences (SPSS). The data include the following information: type of food commodity, number of samples tested, number of samples with and without pesticide residues, and type of pesticide residue. The data were analysed as numbers and percentages. To examine whether there is a statistically significant association between the sample's origin (local vs. imported) and the sample result (satisfactory vs. unsatisfactory), Fisher's Exact Test was performed, as one of the expected cell counts was less than 5.

H_0 : There is no association between sample origin and sample result.

H_1 : There is an association between sample origin and sample result.

In contrast, the Likelihood Ratio Chi-square Test (G-test) was applied to assess whether there is a statistically significant association between the sample type and the sample result. This test was chosen because one of the expected cell counts in the contingency table is less than 5.

H_0 : There is no association between sample type and sample result.

H_1 : There is an association between sample type and sample result.

3. Result

Five hundred twenty-two samples from local and imported food commodities were analysed at PHL. The samples were categorized by type into three groups: vegetables and fruits, spices, and other types, and by sample's origin into local and imported.

The "other" food category comprises many items spanning multiple food groups. This group includes items from several distinct categories, such as meat

and poultry products (e.g., chicken, beef steak, eggs), beverages (e.g., various teas and coffees), processed and frozen foods (e.g., frozen chicken, cake, vine leaves), nuts and seeds (e.g., cashews, pistachios, peanuts), and grain-based products (e.g., flour, rice). Some preserved or specialized items, like oil and canned products, are also included. Although each item belongs to a recognizable food category, the diversity within this group and the low frequency of individual items necessitated their classification into a separate “other” category. This approach preserves analytical clarity and ensures the study remains focused on its primary objective: examining consumption patterns of fruits, vegetables, and spices.

121 (23%) samples were collected from local commodities, and 401 (77%) samples were imported commodities. Out of 522 samples tested, pesticide residues were detected in 175 (34%) samples, 31% (n = 55) of the detected samples were from local food commodities, while 69% (n = 120) were imported food commodities. Among samples with detected pesticide residues, 19% (33) were vegetable and fruit samples, 59% (104) were spices samples, and 22 % (38) were found in other types (Table 2). Among samples with detected pesticide residues, only 9% (n = 15) were evaluated as unsatisfactory according to the national standards, where pesticide residue with a concentration more than the MRL. Figure 1 below summarizes the results for all samples per MRL.

Table 2. Food commodity categories distributed by type, origin of samples, and presence of pesticide residue.

Food commodity categories	Imported (n = 401)		Local (n = 121)		Total (n = 522)	
	Without residue	With residue	Without residue	With residue	Without residue	With residue
Vegetables and Fruits	96	18	21	15	117	33
Spices	41	70	21	34	62	104
Other types	144	32	24	6	168	38
Total	281	120	66	55	347	175

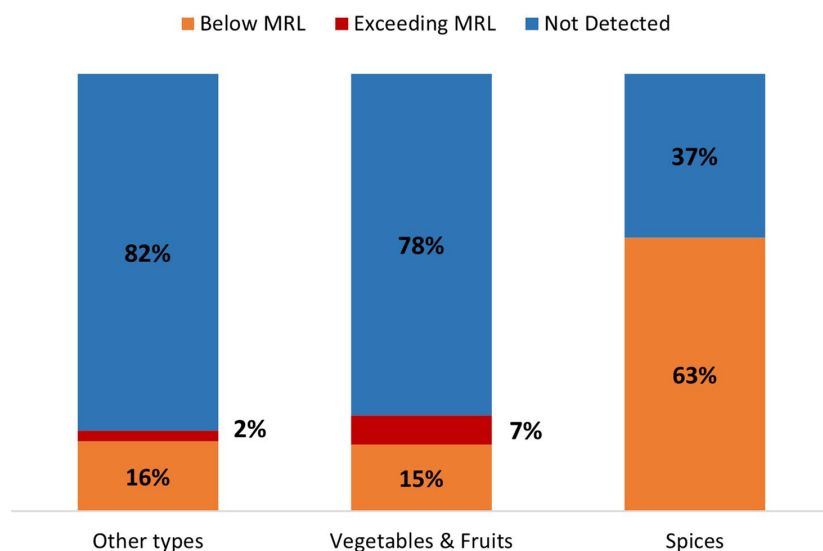


Figure 1. Detection results for all samples per MRL limit.

Seventy-six pesticides were detected (**Table 3**), of which 58 (76%) were organophosphates and 18 (24%) were organochlorines. Most detected samples (69%, $n = 121$) contained two or more pesticide residues, while 54 (31%) samples contained a single residue. Twenty-four types of pesticides detected in food were not included in the Gulf Cooperation Council (GCC) standard of pesticide residues in food commodities.

Table 3. Summary of the 76 detected pesticide residues and their respective frequency of occurrence.

Detected Pesticides (Frequency)	Detected Pesticides (Frequency)	Detected Pesticides (Frequency)	Detected Pesticides (Frequency)
Endosulfan II (β) (53)	Dieldrin (8)	4,4-DDE (2)	PROPACHLOR (1)
2,4-DDD (39)	METHAMIDOPHOS (8)	ETHOFUMESATE (2)	PROPICONAZIDE (1)
AZOXYSTROBIN (35)	IAMAZALIL (8)	ISOCARBOFOS (2)	PYRIDAPHENTHION (1)
2,4-DDT (30)	CARBOFURAN (6)	LENACIL (2)	DIMOXYSTROBIN (1)
Endrin aldehyde (29)	PYRIPROXIFEN (6)	TEBUFENOZIDE (2)	METOLCARB (1)
Endrin ketone (28)	DAMINOZIDE (5)	CARBENDEZIME (2)	FENAZOX (1)
Endrin (27)	DIFENOCONAZOLE (5)	PROPAZINE (2)	PYROQUILON (1)
MYCLOBUTANIL (26)	SIMRTRYN (5)	TRIADIMENOL (2)	HEPTENOPHOS (1)
4,4-DDT (22)	b-HCH (4)	FENAZAQUIN (2)	ESPROCARB (1)
Heptachlor epoxide (20)	AZOBENZEN (4)	PICOXYSTROBIN (2)	METHOMYL (1)
METALAXYL (17)	DISULFOTON-SULFONE (4)	PROMECARB (2)	LINDANE (1)
Endosulfan I (α) (16)	METHACRIFOS (4)	CYROMAZINE (2)	FENPYROXIMAT (1)
PROPICONAZOLE (14)	DIMETHANEAMIDE (4)	SIDURON (2)	TERBUTHYLAZINE-2-HYDROXY (1)
PROPHAM (12)	CADUSAFOS (3)	PYRIMETHANIL (2)	FUROBINOCARB (1)
a-HCH (10)	IPROVALICARB (3)	Boscalid (2)	ISOPROCARB (1)
Aldrin (10)	DIPHENYLAMINE (3)	Endosulfan sulfate (1)	ACEPHATE (1)
2,4-DDE (10)	PROPOXUR (3)	FENURON (1)	CLETHODIM (1)
4,4-DDD (9)	CLOTHIANIDIN (3)	FENPROPIDIN (1)	Hexythiazox (1)
AMITROLE (9)	Heptachlor (2)	METOLCARB (1)	THIOPHANATEMETHYLE (1)

Fisher's Exact Test yielded a non-significant result ($p = 0.758$), greater than the conventional significance level of 0.05. This indicates no statistically significant relationship between the sample's origin and the result. These findings suggest that the sample's origin did not directly impact whether it was classified as satisfactory or unsatisfactory. On the other hand, the G-test yielded a statistically significant result ($p = 0.001$), which is less than the standard significance level of 0.05. This suggests that sample results differ significantly across product types, indicating a meaningful association between the type of sample and the likelihood of it being classified as satisfactory or unsatisfactory.

3.1. Pesticide Residues in Local Farms (Local Fruit and Vegetables)

Thirty-six local farm vegetable samples were analyzed, and pesticide residues were detected in 15 (42%) samples. Twelve pesticide residues were detected, 9 (75%) of which were organochlorines and 3 (25%) were organophosphates. Levels in 4

(11%) exceeded the MRLs. The most common pesticide residues detected in the local farm crops, as shown in **Table 4**, were endrin (15%), endrin ketone (15%), alpha-HCH (12%), and amitrole (12%).

Table 4. Types of pesticides detected in local farm crops according to frequency of occurrence.

Pesticide Type	Frequency
Endrin	5
Endrin ketone	5
alpha-HCH	4
Amitrole	4
beta-HCH	2
Aldrin	2
Endosulfan I (<i>a</i>)	2
2,4-DDT	2
4,4-DDT	2
2,4-DDD	2
Azobenzen	2
Triadimenol	1

3.2. Pesticide Residues in Imported Vegetables and Fruits

One hundred and fourteen samples of imported vegetables and fruits from 16 countries were analysed (**Figure 2**), and residues were found in 18 (16%) samples. Fifteen pesticide residues were detected, 6 of which were organochlorines and 9 were organophosphates. According to the GCC standards, authorized pesticide residues were detected in 12 (11%) samples. Six (5%) food samples contained at least one unauthorized pesticide residue or an authorized residue exceeding the MRL. Approximately 44% of the samples with detected pesticide residues were imported from Egypt and Turkey. The highest percentage of pesticides detected in imported vegetables and fruits was myclobutanil (19%), followed by azoxystrobin and metalaxyl (13%), as shown in **Table 5**.

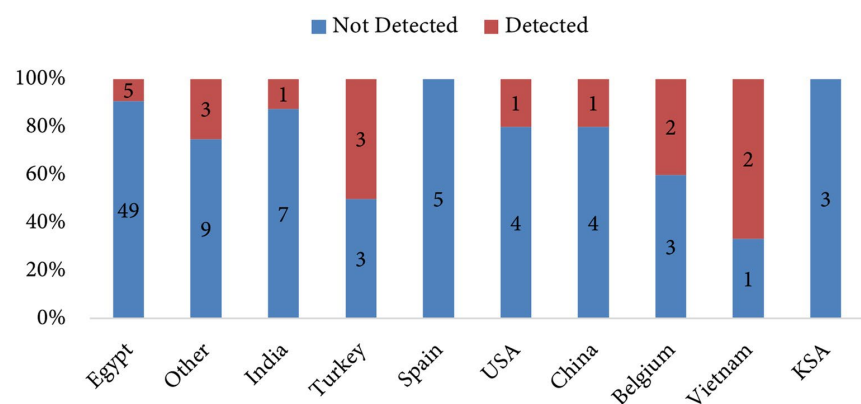


Figure 2. The origins of imported vegetable and fruit samples (3 or more) with detected levels of pesticide residues.

Table 5. Type of pesticides detected in imported fruits and vegetables.

Pesticide Type	Frequency
Myclobutanil	6
Azoxystorbin	4
Metalaxyl	4
Dimethaneamide	3
Pyrimethanil	2
Boscalid	2
Endosulfan II (β)	2
Triadimenol	1
Difenoconazole	1
Hexythiazox	1
Aldrin	1
Endosulfan I (α)	1
4,4-DDT	1
2,4-DDE	1

3.3. Pesticide Residues in Locally Manufactured Spices

Thirty-four (62%) samples from the 55 locally manufactured spices contained pesticides. Endosulfan II (β), 2,4-DDD, and 2,4-DDT were the most common percentages of 17% (19 samples), 16 % (18 samples), and 11 % (10 samples), respectively (Table 6). All samples were evaluated as satisfactory based on GCC standards.

Table 6. Top 10 types of pesticides detected in local manufactured spices.

Pesticide Type	Frequency
Endosulfan II (β)	19
2,4-DDD	18
2,4-DDT	11
Endrin ketone	5
Azoxystorbin	5
Heptachlor epoxide	4
Endrin aldehyde	4
Metalaxyl	4
4,4-DDT	3
Dieldrin	2

3.4. Pesticide Residues in Imported Spices

One hundred eleven samples were collected from imported spices, and pesticide residues were found in 63% (70 samples). Forty-two (60%) of the detected samples were imported from India, as shown in Figure 3. Azoxystrobin (25 samples) and Endosulfan II (β) (24 samples) were the most predominant (Table 7). All samples were evaluated as satisfactory based on GCC standards.

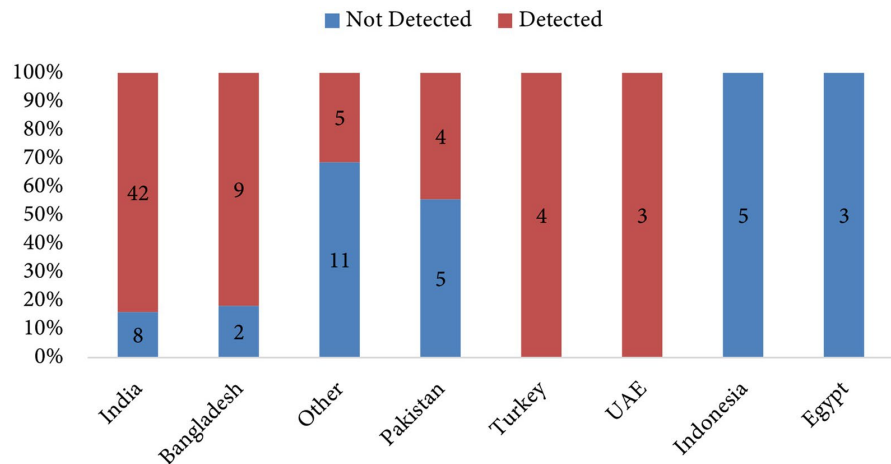


Figure 3. The origins of imported spice samples (3 or more) with detected levels of pesticide residues.

Table 7. Top 10 pesticides detected in imported spices.

Pesticide Type	Frequency
Azoxystorbin	25
Endosulfan II (β)	24
2,4-DDT	14
4,4-DDT	14
Endrin	13
2,4-DDD	13
Endrin aldehyde	12
Myclobutanil	12
Endrin ketone	11
Propham	10

3.4.1. Pesticide Residues in Other Local Commodities

Thirty samples from other local commodities such as cereal, water, and bread were tested, and pesticide residues were found in 20% (6 samples), with endrin aldehyde and endrin ketone being the most common pesticides at 19% (3 samples).

3.4.2. Pesticide Residues in Other Imported Commodities

A total of 176 samples collected from other imported food commodities such as cereals, nuts, tea, coffee, honey, water, cooked food, and juices, and pesticide residues were detected in 32 (18%) of the samples. Based on GCC standards, only 3% (5 samples) had unsatisfactory residue levels. Although endrin pesticide is banned in many countries, endrin aldehyde and endrin were detected in the imports at 11% and 9%, respectively. About 28% of the positive samples were imported from India and 20% from Turkey (Figure 4).

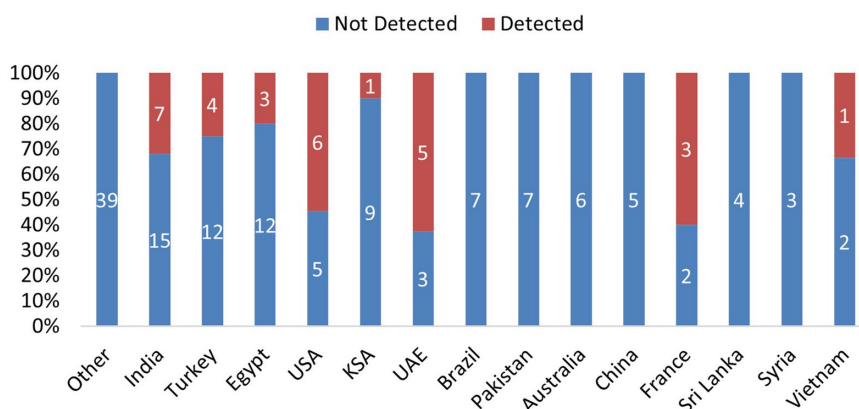


Figure 4. The origins of other imported commodity samples (3 or more) with detected levels of pesticide residues.

4. Discussion

Among the 175 samples tested, 9% exceeded the MRL set by national standards, indicating potential misuse of pesticides. Residues were primarily detected in green leafy vegetables in locally produced food and other directly consumed produce, raising health concerns. Pesticide residues in food, particularly those exceeding maximum residue limits (MRLs), pose significant health risks to consumers. Chronic exposure to such residues has been linked to a range of adverse health effects, including endocrine disruption, neurotoxicity, carcinogenicity, and reproductive disorders [3].

Unsatisfactory levels in local samples (11%) may reflect gaps in farmer knowledge regarding proper pesticide dosages, application techniques, and the recommended interval between treatment and harvest [6] [17]. Additionally, the absence of national guidelines for pesticide use and best agricultural practices likely contributes to the persistence of residues in locally grown crops.

The most common pesticide residues detected in the local farm crops were Organochlorine Pesticides (OCPs) which are persistent organic pollutants (POPs) that have received worldwide attention due to their mutagenic, teratogenic, or carcinogenic characteristics and their resistance to degradation in the environment [10], although only 9% of the samples have exceeded the legal limits of pesticides residue the presence of these substances in food had its consequences. The risk could be due to pesticides that are not readily soluble and could accumulate in organisms' tissues, leading to serious health issues [18]. Persistent organic pollutants (POPs), such as certain organochlorine pesticides, are of particular concern due to their bio-accumulative nature and long-term persistence in human tissues and the environment [4] [18]. Studies conducted in various countries, including China, Pakistan, and Kuwait, have reported detectable levels of multiple pesticide residues in commonly consumed fruits and vegetables, with some samples exceeding established safety thresholds [6] [7] [17]. The accumulation of such residues in adipose tissues further underscores the potential for long-term health consequences [18]. Prolonged exposure to pesticide residues is associated with serious

health issues, including endocrine disruptions, neurotoxicity, reproductive harm, and heightened cancer risk [3] [18]. Persistent organic pollutants (POPs), such as certain organochlorine pesticides, pose additional concern due to their long-term environmental persistence and bioaccumulation in human tissues [4] [19]. Similar concerns have been raised globally, with studies from China, Kuwait, and Pakistan reporting the presence of pesticide residues in commonly consumed produce [6] [7] [17].

Additionally, improper pesticide application and weak regulatory enforcement can exacerbate the risks, especially in developing regions where awareness and monitoring may be limited [2]. As the global demand for agricultural output continues to rise [1], ensuring food safety through stringent monitoring and adherence to international pesticide residue standards is imperative for protecting public health.

Only six (5%) food samples contained at least one nonauthorized pesticide residue or an authorized pesticide residue exceeding the maximum limit for human use. The occurrence of such multiple residues is likely to be a consequence of the application of different types of pesticides to protect the crops from various insects/diseases, which reflects improper practices of some farmers in using pesticides to combat agricultural pests. The highest percentage of pesticides detected in imported vegetables and fruits was Myclobutanil (19%), followed by Azoxystrobin (13%), fungicides used in agriculture to protect crops from fungal diseases. Therefore, it is essential to monitor pesticide residues continuously in all imported crops (imported from both developing and non-developing countries) to ensure food safety and security at our local market.

Although all local and imported spices samples in this study have been evaluated satisfactorily, the findings showed that spices samples consistently exhibited the highest percentage of detected pesticide residues (59.4%) compared to other food categories. This highlights the critical importance of re-evaluating national limits for pesticides such as Endosulfan II (β), 2,4-DDD, AZOXYSTORBIN, Endrin aldehyde, and 2,4-DDT. Given their prevalence, national limits for these pesticides must be thoroughly reviewed and possibly revised. Consequently, continued monitoring and regulation are essential to minimize the risks posed by their use and ensure the safety of ecosystems and public health.

The rate of samples detected with pesticide residues exceeding MRL in local samples is 3.3%, which is consistent with the findings of the Pesticide Residue Monitoring Program in the USA for 2014 - 2020, where the rate of samples detected with pesticide residues exceeding MRL ranged from 0.9% - 3.8%, according to the annual report of Pesticide Residue Monitoring Program issued by the U.S. Food and Drug Administration (FDA) [20]. Regarding imported samples, 2.7% of the samples were detected with pesticide residues exceeding MRL, which is below the rate of USA samples as per the annual report of Pesticide Residue Monitoring Program issued by FDA for 2014 - 2020, where the rate of imported samples detected with pesticide residues exceeding MRL ranged from 9.4 to 12.9% [20].

Overall, 2.9% of the tested samples were detected with pesticide residues exceeding MRL, which is below the result of the 2019 European Union report on

pesticide residues in food issued by the European Food Safety Authority (EFSA), where 3.9% of the test samples exceeded MRL [21].

5. Conclusions

This study investigated the presence and levels of pesticide residues in Bahrain's locally produced and imported food commodities over five years. The results indicated that most food commodities (66%) did not contain detectable pesticide residues. An additional 31% of the samples contained residues below the maximum residue limits (MRLs), which are considered safe for consumption. Only 3% of the samples exceeded MRLs, suggesting that pesticide contamination is not a significant public health concern in Bahrain. Although the prevalence of hazardous residues was low, the health risks associated with pesticide exposure, particularly in samples exceeding MRLs, should not be overlooked.

The effectiveness of OCPs in pest control is undeniable; however, their long-term consequences highlight the need for stricter regulations, sustainable alternatives, and ongoing monitoring. Continued efforts are essential to regularly test pesticide levels in imported and locally grown foods, reflecting the importance of understanding and improving agricultural practices. Future research and international collaboration are crucial to mitigating health risks while supporting farm productivity and environmental safety.

Acknowledgements

The authors are very grateful to the Public Health Laboratory Reference Lab—Ministry of Health—Bahrain, especially the chemical analysis group, for their helpful work and data provision.

Conflicts of Interest

The authors declare that no competing personal or financial interest could have appeared to influence the work illustrated in this paper.

References

- [1] Alexandratos, N. and Bruinsma, J. (2012) World Agriculture towards 2030/2050: The 2012 Revision. ESA Working Paper No. 12-03. FAO.
- [2] Kumar, S., Sharma, A.K., Rawat, S.S., *et al.* (2013) Use of Pesticides in Agriculture and Livestock Animals and Its Impact on the Environment of India. *Asian Journal of Environmental Science*, **8**, 51-57.
- [3] World Health Organization (2018) Pesticide Residues in Food. <https://www.who.int/news-room/fact-sheets/detail/pesticide-residues-in-food>
- [4] Lallas, P.L. (2001) The Stockholm Convention on Persistent Organic Pollutants. *American Journal of International Law*, **95**, 692-708. <https://doi.org/10.2307/2668517>
- [5] Stachniuk, A., Szmagara, A., Czecko, R. and Fornal, E. (2017) LC-MS/MS Determination of Pesticide Residues in Fruits and Vegetables. *Journal of Environmental Science and Health, Part B*, **52**, 446-457. <https://doi.org/10.1080/03601234.2017.1301755>
- [6] Jallow, M., Awadh, D., Albaho, M., Devi, V. and Ahmad, N. (2017) Monitoring of

- Pesticide Residues in Commonly Used Fruits and Vegetables in Kuwait. *International Journal of Environmental Research and Public Health*, **14**, Article 833. <https://doi.org/10.3390/ijerph14080833>
- [7] Chen, C., Qian, Y., Chen, Q., Tao, C., Li, C. and Li, Y. (2011) Evaluation of Pesticide Residues in Fruits and Vegetables from Xiamen, China. *Food Control*, **22**, 1114-1120. <https://doi.org/10.1016/j.foodcont.2011.01.007>
- [8] Ministry of Information (2024) Location and Resources. <https://www.mia.gov.bh/kingdom-of-bahrain-ar/location-and-natural-resources-ar/>
- [9] Ministry of Health, Food Control Section (2022) Imported Food Guideline in Bahrain. https://www.moh.gov.bh/Content/Upload/File/638242462505257319-imported-food-guide-line-in-bahrain-english-version_AR.pdf
- [10] Ministry of Health (5025) Pesticides E-Services. Kingdom of Bahrain. <https://www.moh.gov.bh/eServices/Pesticides?lang=e>
- [11] Ministry of Municipalities Affairs and Agriculture (2025) Obtaining a License to Import Agricultural Pesticides and Public Health Chemicals. <https://www.mun.gov.bh/newportal/index.php/en/agriculture-marine-resources-affairs/services/obtaining-license-import-agricultural-pesticides-and>
- [12] SGS Bahrain (2025) Pesticide Residue Studies. <https://www.sgs.com/en-bh/services/pesticide-residue-studies>
- [13] Stockholm Convention (2020) Bahrain Submits 30 Import Responses. Rotterdam Convention—Prior Informed Consent. <https://www.pic.int/Implementation/PublicAwareness/NewsFeatures/Bahrainsubmits30importresponses/tabid/5013/language/en-US/Default.aspx>
- [14] UNITAR (2019) National Profile of Chemical Management in the Kingdom of Bahrain (Updated) United Nations Institute for Training and Research. https://cwm.unitar.org/national-profiles/publications/cw/np/np_pdf/Bahrain_National_Profile_update.pdf
- [15] Ministry of Health—Kingdom of Bahrain (2023) Food Sampling Quality Assurance Policy: Prepared by the Food Control Section. Food Control Section, Ministry of Health.
- [16] Codex Alimentarius Commission (1999) Recommended Methods of Sampling for the Determination of Pesticide Residues for Compliance with MRLs (CAC/GL 33-1999). <https://heyzine.com/flip-book/44d76cfa82.html>
- [17] Latif, Y., Sherazi, S.T.H. and Bhanger, M.I. (2011) Monitoring of Pesticide Residues in Commonly Used Fruits in Hyderabad Region, Pakistan. *American Journal of Analytical Chemistry*, **2**, 46-52. <https://doi.org/10.4236/ajac.2011.228123>
- [18] Wang, N., Shi, L., Kong, D., Cai, D., Cao, Y., Liu, Y., *et al.* (2011) Accumulation Levels and Characteristics of Some Pesticides in Human Adipose Tissue Samples from Southeast China. *Chemosphere*, **84**, 964-971. <https://doi.org/10.1016/j.chemosphere.2011.05.062>
- [19] Zhang, Y., Qi, S., Xing, X., Yang, D., Devi, N.L., Qu, C., *et al.* (2024) Legacies of Organochlorine Pesticides (OCPs) in Soil of China—A Review, and Cases in Southwest and Southeast China. In: De Vivo, B., Belkin, H.E. and Lima, A., Eds., *Environmental Geochemistry*, Elsevier, 519-547. <https://doi.org/10.1016/b978-0-443-13801-0.00015-3>
- [20] U.S. Food and Drug Administration (FDA) (2023) Pesticide Residue Monitoring Report and Data for FY 2021.

<https://www.fda.gov/food/pesticides/pesticide-residue-monitoring-report-and-data-fy-2021>

- [21] European Food Safety Authority (EFSA) (2021) The 2019 European Union Report on Pesticide Residues in Food. <https://www.efsa.europa.eu/en/efsajournal/pub/6491>