ISSN: 2572-4061

Alqahtani et al. J Toxicol Risk Assess 2023, 9:056
DOI: 10.23937/2572-4061.1510056
Volume 9 | Issue 1
Open Access

Journal of
Toxicology and Risk Assessment

RESEARCH ARTICLE

Determination of Pesticide Residues in Leafy Vegetables and Dietary Risk Assessment

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Abstract

The consumption of leafy vegetables has increased worldwide due to increasing consumer awareness of their nutritional value. Consumers are likely at risk since leafy vegetables are often consumed raw. This research aim was to assess the potential health risks using Saudi Food and Drug Authority (SFDA) [1] inspection and monitoring program data. This study assessed the risks of pesticide residues from the consumption of leafy vegetables (watercress, spinach, mallow, vine leaves, and lettuce) by Saudi adults, and based on data availability, these crops were selected. The health risk was evaluated in both terms: The acute health risk was based on the estimated short-term intake (EST) assessment for a single commodity over 24 hours. Cancer and non-cancer (long-term risk) calculation for hazard quotient (HQ) and incremental lifetime cancer (ILCR) depended on the estimated daily intake (EDI). The examined results showed that the acute risk related to constipation of lettuce, spinach, and watercress were within the safe limit for biphenyl, cypermethrin, linuron, methomyl, oxadiazon, and pendimethalin. Regarding the cancer risk, the ILCR was between 1.30E-06- C 3.38E-04. For the Non-Cancer risk, HQ was.1.3E-2- 6.76 E-4, and the exhibited hazard of cumulative risk was below 1. Based on the obtained results for chronic and non-chronic risk, values complied with acceptable limits concluding that there is no hazard associated with the consumption of tested leafy vegetables for the Saudi population.

Keywords

Pesticide residues, Leafy vegetables, Risk assessment, Acute risk, Chronic risk, Non-chronic risk

Introduction

The global consumption of leafy vegetables (raw, boiled, or steamed) accounts for 2% of total vegetable consumption. Furthermore, they are believed to have a more significant health impact than cereals [2]. In the modern world, green leafy vegetables are a good source of essential vitamins, minerals, and antioxidants, making them an important component of a vegetarian diet [3,4]. Green leafy vegetables are more susceptible to environmental changes and pest attacks. The use of greenhouses can reduce the adverse effect on the environment, while pesticides are generally used to prevent pests from attacking vegetables [5].

Recently, monitoring studies [6,7] conducted in Saudi Arabia reported vegetables containing pesticide residues that exceed the MRL. Among the commonly used pesticides on green leafy vegetables are monocrotophos (MONO), dichlorvos (DCV), chlorpyrifos (CPS), profenofos (PFF), and cypermethrin (CP) [5].

Many consumers prefer raw vegetables over cooked, which are sometimes considered unsafe due to pesticide residues even after washing [8]. Several problems are associated with consuming food containing pesticide residues, which can have acute or chronic effects on the health of individuals exposed to them, depending on the quantity and manner of exposure. Due to their potential toxicity, pesticides may cause adverse health effects on the immune system, nervous system, reproduction, and cancer [9]. As the use of pesticides

Citation: Alqahtani D, Al-Mutairi M, Alrashed N, Alajmi R, Alowaifeer A (2023) Determination of Pesticide Residues in Leafy Vegetables and Dietary Risk Assessment. J Toxicol Risk Assess 9:056. doi.org/10.23937/2572-4061.1510056

Accepted: December 23, 2023: **Published:** December 25, 2023

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in crops and plants has increased globally, consumer safety has become a concern [8]. Therefore, health risk studies associated with pesticide exposure via food are necessary. Previous research on risk assessment on leafy vegetables was done by [8] in South Korea [10] in Turkey, and [11] in Chile. In Saudi Arabia, there is a lack of information on the health risk assessment of pesticide exposure through food. However, a few studies assessed the risk of pesticide residues [12] in vegetables [13] in fruit and vegetables. Studies on determining the potential health risk of pesticide residues in leafy vegetables on consumers' health are essential due to the nutritional value of leafy vegetables provided for the human diet and the increased vegetarian food demand. This research aimed to evaluate the acute risk during a day in addition to potential cancer and non-cancer risks of pesticide residues for a long time by consuming leafy vegetables (vineleaves, spinach, lettuce mallow, and watercress) in the SFDA inspection and monitoring program data.

Materials and Methods

Samples with multiple residues

Data of 1300 samples of leafy vegetables, including vine leaves, spinach, lettuce mallow, and watercress, was provided by the SFDA inspection and monitoring programs in Riyadh, Dammam, and Jeddah cities. Samples were collected between 2018 and 2020 from various markets and greenhouses for each lab. SFDA-accredited laboratories received one kilogram of each fresh leafy vegetable sealed in polyethylene bags for pesticide analysis.

Sample preparation and analysis

The extraction of pesticides in leafy vegetable samples was carried out following the QuEChERS method (EN 15662:2009-02). 10g of homogenized sample was weighed and placed in a polypropylene tube, then 10 ml of acetonitrile was added to the mixture and shaken. Afterward, A QuEChERS salt containing 4g of magnesium sulfate and 1g of sodium chloride was added up, and the sample was shaken vigorously for 2 min, then centrifuged for 5 min at > 5000 rpm. An aliquot of the organic phase was cleaned-up using a dispersive solid-phase extraction (D-SPE) employing bulk sorbents (primary, secondary amine sorbent) and magnesium sulfate. The mixture was shaken vigorously for 2 min and centrifuged for 5 min at > 5000 rpm. The eluent was then filtrated using a 0.2 µm filter, and vials were injected into both instruments. Agilent Gas chromatography-mass spectrometer (GC-MS/MS) equipped with DB-5 MS column (5% phenyl 95% dimethylarylene siloxane, Agilent, USA) and Qtrap 6500 AB Sciex liquid chromatography-mass spectrometry (LC-MS/MS) with a ZORBAX Eclipse Plus C18 column.

The analytical method for determination of pesticide residues in vegetables was validated according to SANTE/11312/2021 requirements [14], validation parameters were deter- mined: linearity, precision, limit of quantification (LOQ) defined according to the lowest spiked level that meets the acceptable accuracy (70-120%). Blank samples spiked with standard solutions three levels 0.01 the Limit of quantification (LOQ), 0.02, and 0.05 mg/kg levels with 5 replicates, to determine the recovery and precision. The linearity was determined by injecting five matrix-matched standards in the concentration range of 0.001-0.1 mg kg^{-1}.

Risk assessment

Assessing the risk of pesticide residues in leafy vegetables for human consumption is necessary to ensure consumer safety. Conceptually, exposure assessment is the human intake of biological, chemical, and physical agents through food [15]. This study assessed the actual exposure of the Saudi population (adults) to pesticide residues found in leafy vegetables consumed, which was performed in two different timeframes: Acute (short-term) and chronic, non-chronic (long-term).

Acute exposure is related to a single meal or over 24 hours. ESTI calculation is based on the highest reported 97.5^{th} percentile intake during a day by individual consumers reported by countries with such individual consumption data (GEMS/Food databases) [16]. The assessment was performed by EFSA, cosponsored by FAO/ WHO (EFSA and RIVM, 2015) [17] for a pesticide residue with Acute Reference Dose (RfD).

The calculation of leafy vegetables involving; spinach, lettuce, and watercress was calculated using Case 2a (for food with a unit weight of the edible portion (Ue) is lower than that of the large portion (LP) (FAO, 2016). However, vine leaves and mallow do not have the highest reported 97.5th percentile intake data [18] Calculated as follows:

$$ESTI = \frac{Ue \times (HR) \times v \times (LP - Ue) \times HR}{bw} \quad (1)$$

Where bw is body weight (kg), HR is the Highest residue in the composite sample (mg kg^{-1}) as reported, Ue is the Unit weight of edible portion (kg) which was 0.255, 0.090, and 0.118: And Large portion Kg/person with reported value of 0.091, 0.179, and 0.1598, V is the variability factor was 3 for watercress, spinach, lettuce, separately. The percentage of acute RfD evaluates acute health risks for the general population; then the exposure is compared to safe doses of ARfD; when %RfD is below %100 the consumer is considered safe, whereas %RfD above %100 consumer is unsafe (IEST guideline) the relevant formulas are as following:

$$\%RfD = \frac{ESTI}{ARfD} \times 100 \quad (2)$$

For long-term risk assessment, the EDI of pesticide residues via leafy vegetables was applied using USEPA (2011) [19] guidelines, expressed in $mgkg^{-1}$ body weight (bw) day^{-1} and calculated according to the following equation:

$$EDI = \frac{C \times EF \times ED \times IR}{AT \times BW} \quad (3)$$

Where C is the concentration of pesticide residues in leafy vegetables (mg kg^{-1}), the mean of each pesticide used, EF is the exposure frequency (365 days $year^{-1}$), ED is the exposure duration (years), which is 30, and 54 years for adult non-cancer and cancer according to MOH and USEPA, respectively. IR is the ingestion rate of leafy vegetables including (0.113 kg per person day^{-1}), AT is the average exposure time (365-day $year^{-1}$ × 75 years), and BW is the average body weight for adults (75 kg/person).

The Long-term risk was assessed by comparing the intake to toxicological values where the probabilities of cancer and non-cancer hazard were calculated as described in [20] both ILCR and HQ was evaluated based on the following formulas:

$$ILCR = EDI \times CSF \quad (4)$$

ILCR evaluated using oral cancer slope factors (CSF), ILCR reflects the probability of an individual developing cancer. ILCR value classified by USEPA, the value between 10^{-8} - 10^{-6} is considered negligible, whereas 10^{-6} - 10^{-4} is regarded as the maximum acceptable level, and a value above 10^{-4} is an unacceptable carcinogenic health risk.

$$HQ = \frac{EDI}{ADI} \quad (5)$$

ADI indicates the concentration of pesticide residues that can be eaten over a long period without having unacceptable negative health impacts. According to USEPA, HQ values equal to or less than one means the unlikely population would be exposed to health risks, while HQ more than one means there could be a non-cancer risk.

$$HI = \sum HQ \quad (6)$$

HI, values represent the total HQ of all residues, and health risk calculation was reported at %95 percentile following the probabilistic stimulation. Monte Carlo simulation (MICROSOFT OFFICE EXCEL 2013) was used in 10,000 replicates to account for variability for C mean stander deviation was used and (± 20) uncertainty for IR and bw worst-case scenario.

Result and Discussion

Samples with multiple residues

The result of quality control for the analytical methods are listed in Table 1, the LOQ are 0.1 mg/kg for all examined pesticides and recovery for all examined pesticides are within the acceptable range 70-120% according to SANTE Guideline criteria. Leafy vegetable analyzing samples included watercress (12%), spinach (16%), mallow (21%), vine leaves (26%), and lettuce (25%). A detectable pesticides residue from different

Table 1: Pesticides RfD, ADI, LOQ, and Recovery %.

Analyte	RfD (mg kg^{-1} day^{-1})	ADI (mg kg^{-1} bw^{-1})	LOQ ppb	Recovery %
Acetamiprid	-	0.07	10	90.41
Azoxystrobin	-	0.2		94.27
Boscalid	-	0.04		100.24
Biphenyl	5×10^{-1}	-		108.49
Carbendazim	-	0.03		86.95
Chlorpyrifos	-	0.01		96.58
Cypermethrin	1×10^{-2}	0.02		96.73
Imidacloprid	-	0.06		87.19
Methomyl	2.5×10^{-2}	0.02		104.2
Myclobutanil	-	0.03		80.54
Linuron	2×10^{-3}	-		77.04
Oxadiazon	5×10^{-3}	-		98.23
Pendimethalin	-	-		101.22
Pyrimethanil	4×10^{-2}	0.2		73.48
Kresoxim-Methyl	-	0.3		104.55
Penconazole	-	0.03		90.83
Tebuconazole	-	0.03		87.49

The source of RfD values is (EPA), The source of ADI values is JMPR

Acute RfD: AcuteReference Dose, ADI: Acceptable Daily Intake

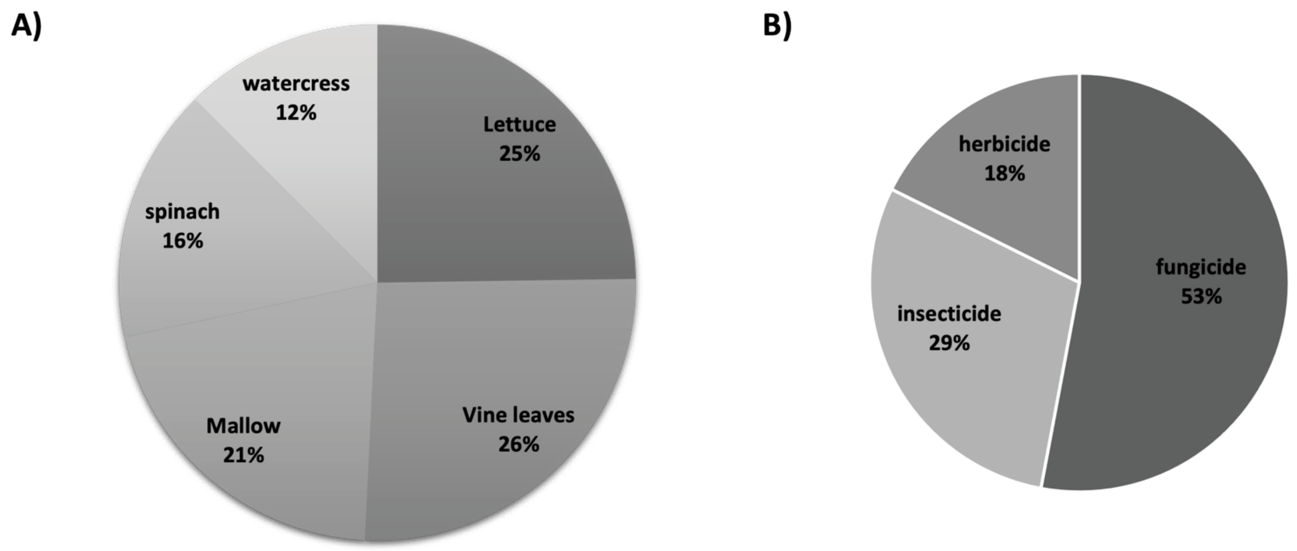

Figure 1: (A) Sorting of leafy vegetable samples by crops and (B) Classification of pesticides by targeted organism.

chemical groups were classified based on the targeted organism as 53% fungicide, %29 insecticide, and 18% herbicide Figure 1. A total of 17 pesticide residues were detected in the leafy vegetables, including acetamiprid, azoxystrobin, boscalid, biphenyl, carbendazim, chlorpyrifos, cypermethrin, imidacloprid, methomyl, myclobutanil, linuron, oxadiazon, pendimethalin, pyrimethanil, kresoxim-methyl, penconazole, and tebuconazole. Acute risk assessment pesticides with an established RfD value were biphenyl, cypermethrin, linuron, methomyl, oxadiazon, and pendimethalin. The concentrations range was between 0.022-10.73 mg kg^{-1}, where the maximum concentrations belong to biphenyl in watercress. Based on the result, the frequently detected pesticides with more than ten replicates were examined for long-term risk: Acetamiprid, azoxystrobin, biphenyl, boscalid, carbendazim, and chlorpyrifos. The most frequently detected pesticide in leafy vegetables was acetamiprid, with a detection rate of 57%, while cypermethrin was the least detected at 11%.

Comparing pesticide levels to SFDA MRL, the detected methomyl exceeds the MRL in lettuce, whereas some compounds do not have MRL in SFDA specification for some leafy vegetables. However, other pesticides do not have any limits on the leafy vegetables studied. Indeed, more pesticides need to be included in local specifications to enhance the ability of pesticide exceedance decisions in leafy vegetables and other crops.

Similar monitoring studies conducted in Saudi Arabia detected pesticides in leafy vegetables. [6] Reported that out of one hundred-sixty examined leafy vegetable samples, eighty-nine contained residues, whereas fifty-three exceeded the maximum residue levels (MRLs). Twenty-three pesticides were identified Carbaryl, biphenyl, and carbofuran was reported as the most frequently detected pesticides [21]. All examined leafy vegetable samples contained pesticide residues from different chemical groups; most pesticide residue levels were low, but some had higher levels of pesticides. The rocket (Eruca sativa) had higher levels of chlorpyrifos (0.123 mg kg^{-1}) and resmethrin (0.1 mg kg^{-1}), spinach had carbaryl (0.92 mg kg^{-1}, and mallow had carbaryl (0.116 mg kg^{-1}) residues, permethrin in lettuce, coriander, and parsley, and cypermethrin in parsley (0.126 mg kg^{-1}).

Health risk assessment

This work assesses the potential health risks (short-long and -term) impact from using leafy vegetables in the Saudi population (adult). Residue data was accumulated using SFDA inspection and monitoring programs. Consumption of leafy vegetables was challenged due to the need for a food database for the Saudi population; therefore, several sources were used to collect this data (GEMS/Food databases) [16] and the Saudi General Authority for Statistics (GSTATS) [22]. The health risk was evaluated in both terms: The acute health risk (long term) and Cancer and non-cancer (long-term risk). In acute health risk, the EST assessment was done using deterministic approaches, which focus on only a single commodity at a time based on the highest reported 97.5th percentile intake during a single day calculated, then the result compared to RfD to be evaluated. For estimated daily intake (EDI), the calculated was done using probabilistic approaches, which focus on all leafy vegetables together for an extended period, and the health risk was assessed by calculating HQ and ILCR using ADI and CSF values.

Acute risk assessment (short-term)

IEST calculation of leafy vegetables involving; watercress, spinach, and lettuce were done using Case 2a with involving Ue, LP, V, and HR values in Table 2. The calculated ESTI for methomyl in lettuce was (2.0 E^{-3}); and in spinachlinuron was (2.53 E^{-4}), cypermethrin

Table 2: Pesticides HR, ESTI, and % acute RfD.

Analyte	Lettuce			Spinach			Watercress		
	HR (mg kg^{-1})	ESTI (mg kg^{-1} bw day^{-1})	% Acute RfD	HR (mg kg^{-1})	ESTI (mg kg^{-1} bw day^{-1})	% Acute RfD	HR (mg kg^{-1})	ESTI (mg kg^{-1} bw day^{-1})	% Acute RfD
Biphenyl	-	-	-	-	-	-	10.73	8.6 E^{-2}	17.17
Cypermethrin	-	-	-	0.198	9.5E^{-4}	9.46	0.798	6.3 E^{-3}	63.84
Linuron	-	-	-	0.053	2.5E^{-4}	12.67	0.076	6.1E^{-4}	30.40
Methomyl	0.394	2.0 E^{-3}	8.318	1.021	4.9E^{-3}	19.52	0.063	5.0E^{-4}	2.016
Oxadiazon	-	-	-	-	-	-	0.0489	3.0E^{-4}	7.82
Pendimethalin	-	-	-	-	-	-	0.022	1.7E^{-4}	0.44

HR: Highest Residue, ESTI: Estimated Short-term Intake

(9.46E^{-4}), and methomyl (4.89E^{-2}); The watercress IEST was 1.7E^{-4} - 8.6 E^{-2} whereas the pendimethalin had the lowest and biphenyl the highest value.

The acute health risk was evaluated by the percentage of acute RfD for the general population (adults), as shown in Table 2. The calculated % acute RfD in lettuce methomyl results was within the permitted limit. On the other hand, in spinach, %RfD for cypermethrin, linuron, and methomyl were within the safe limit. In watercress % acute RfD for all pesticides biphenyl, cypermethrin, linuron, methomyl, oxadiazon, and pendimethalin was within the safe limit. A similar study in leafy vegetables [10] reported no potential acute risk for all examined pesticides where as acetamiprid had the highest risk with HQ value of 0.097% in lettuce.

Sometimes the exposure to pesticides during one meal or a day can be higher than average due to consuming considerable portions at meals or more significant residue [23]. Pesticides can pose acute risks after only a short exposure period, such as developmental effects, blood dyscrasias, and neurotoxic effects, such as delayed neuropathy and cholinesterase inhibition [24]. Therefore, the acute RfD for pesticide residue was established, and the acute toxicity endpoint are used to identify which population subgroups are at risk; thus, the risk is predicted using proper food intake and body weight. The UK and the EU provide databases for estimating one-day exposure to acutely toxic chemicals in food. These databases provide important parameters such as large portions of commodities by the various population (general/children and pregnant women), unit weight and percent edible portion, and relevant body weight [22]. JMPR GEMS/Food Consumption Data include different commodities/various populations (general/children and pregnant women), and fourteen countries were involved. Also, data on unit weight and percent edible portion were provided by eleven countries. To accurately estimate the Saudi population's intake, it is critical to consider the highest reported 97.5th percentile with essential information about the Saudi population.

Chronic/non-chronic risk assessment (Long-term)

The acceptable daily intake (ADI) value is used to compare the estimated dietary intake, where ADI indicates the concentration of a chemical that can be eaten over a long period without having unacceptable negative health impacts. All pesticides EDI of leafy vegetables for non-cancer risk was calculated based on a duration of 30 years (Table 3); values were in a range of 4.93E^{-05} - 8.0E^{-4} mg kg^{-1} bw day^{-1} which falls within the acceptable limits (ADI). In terms of exposure, imidacloprid showed the highest value, while chlorpyrifos and acetamiprid had the lowest exposure with relatively similar values.

Furthermore, the estimated target HQ was in the range of 1.3E^{-2} - 6.76 E^{-4}. Pesticides were arranged from the highest to the lowest, imidacloprid, pyrimethanil, chlorpyrifos, cypermethrin, azoxystrobin, penconazole, boscalid, tebuconazole, carbendazim, methomyl, myclobutanil, kresoxim-methyl, and acetamiprid. All HQ values for these pesticides were below 1, which depicts no probability of non-cancer risk through the consumption of leafy vegetables. The total HQ values for examined pesticides was not represented non-cancer hazard, which is expressed as the hazard of cumulative exposure (HI) with value of 0.067, also below (HI < 1).

According to the International Agency for Research on Cancer (IARC), the following pesticides: Acetamiprid, chlorpyrifos, kresoxim-methyl, and carbendazim, were classified as carcinogenic. The estimated daily intakes for cancer risk were calculated based on a duration of 56 years. Obtained values were 3.09E^{-04}, 3.50E^{-04}, 4.80 E^{-04}, and 7.70E^{-04} mgkg^{-1} bw day^{-1} for acetamiprid, chlorpyrifos, kresoxim-methyl, and carbendazim, respectively; which noticeable that carbendazim has the highest exposure rate via leafy vegetables consumes as shown in Table 4.

As for cancer risk evaluated by calculating ILCR, carbendazim, acetamiprid, and chlorpyrifos exhibited 1.76E^{-06}, 2.09E^{-05}, and 3.38E^{-04}, individually were

Table 3: Pesticides ADI, CSF, average concentration, frequencies of detection.

Analyte	Oral slope factor (CSF) (mgkg^{-1}day^{-1})	Mean ± SD (mgkg^{-1})	frequency of detection (%)	LOQ (%)	Recovery (%)
Acetamiprid	7.00E^{-02}	0.160 ± 0.032	57		
Azoxystrobin		0.298 ± 0.089	31		
Boscalid		0.515 ± 0.16	20		
Carbendazim	2.39E^{-03}	0.386 ± 0.103	48		
Chlorpyrifos	1.00E^{+00}	0.181 ± 0.041	29		
Cypermethrin	-	0.335 ± 0.135	11		
Imidacloprid	-	0.283 ± 0.057	43		
Methomyl	-	0.232 ± 0.069	14		
Myclobutanil	-	0.261 ± 0.146	15		
kresoxim-methyl	2.90E^{-03}	0.273 ± 0.077	14		
Penconazole	-	0.337 ± 0.193	19		
Tebuconazole	-	0.341 ± 0.158	15		
Pyrimethanil	-	0.737 ± 0.200	20		

The source of Source of CSF values is RAIS.

*CSF: Cancer Slope Factors, SD: Stander Deviation

Table 4: Pesticides exposure through leafy vegetables and ILCR & HQ values.

Analyte	EDI cancer 95%	ILCR cancer 95%	EDI non-cancer 95%	HQ non-cancer 95%
Acetamiprid	3.09E^{-04}	2.09E^{-05}	4.94E^{-05}	6.76E^{-04}
Azoxystrobin	-	-	9.84E^{-05}	4.70E^{-03}
Boscalid	-	-	1.80E^{-04}	4.30E^{-03}
Carbendazim	7.70E^{-04}	1.76E^{-06}	1.20E^{-04}	3.90E^{-03}
Chlorpyrifos	3.50E^{-04}	3.38E^{-04}	5.70E^{-05}	5.50E^{-03}
Cypermethrin			1.10E^{-04}	5.30E^{-03}
Imidacloprid	-	-	8.0E^{-4}	1.30E^{-2}
Methomyl	-	-	7.60E^{-05}	3.70E^{-03}
Myclobutanil	-	-	9.30E^{-05}	2.90E^{-03}
kresoxim-methyl	4.80E^{-04}	1.30E^{-06}	8.90E^{-05}	2.80E^{-03}
Penconazole	-	-	1.30E^{-04}	4.50E^{-03}
Tebuconazole	-	-	1.28E^{-04}	4.10E^{-03}
Pyrimethanil	-	-	2.40E^{-04}	1.20E^{-02}
HI				6.74E^{-02}

EDI: Estimated Daily Intake, ILCR: Incremental Lifetime Cancer, HQ: Hazard Quotien

considered negligible. However, the kresoxim-methyl ILCR value was 1.30E^{-06} which is within the acceptable level. None of the examined pesticides, acetamiprid, carbendazim, chlorpyrifos or kresoxim-methyl, can pose a carcinogenic risk to consumers of leafy vegetables. Even though the values for long-term risk were calculated based on the worst-case scenario and at 95% percental, this study concludes that Saudi adults have no possible risk (cancer, non-cancer) when consuming leafy vegetables.

Due to a lack of research on risk assessment in the Saudi population on leafy vegetables, thus comparison was performed with other selected results from Saudi work conducted on whole food commodities but including some examined crops or with other countries' studies conducted on leafy vegetables. In Turkey [10] showed that in Lettuce, acetamiprid, and tebuconazole exhibited (EDI) 6.69525E^{-05} and 1.96399E^{-06} mg kg^{-1}d^{-1}. Both analytes' chronic/long-term consumer health risk (HQc) were individually 0.2678 and 0.0065. While in Spinach, acetamiprid has EDI of 9.1335E^{-06} mg kg^{-1}d^{-1} and HQ 0.0365. Another study in South Korea [8] reported that the HI result in spinach was between 1.145455-7.647273 for lufenuron, indoxacarb, and chlorothalonil, whereas HI in Lettucefor procymidone, chlorpyrifos, Lufenuron were 0.875273, 0.232, 0.798442 respectively [13]. Conducted a study in Saudi examined various vegetables, including lettuce and mallow, for general populations, HI and HQ values were all lower than 1

[12]. Mentioned that for both adults and children, the recorded estimated Average Daily Intake EADI values for heptachlor (0.0019 and 0.0022) go beyond the advised ADI (0.0025 and 0.0001 $mg.kg^{-1}.d^{-1}$). The health risk index values for adults and children were higher than 1. Further, all vegetable samples contained heptachlor, aldrin, and heptachlor epoxide with a carcinogenic health risk (HR > 1).

Conclusion

This study observation reveals no acute risk when exposed to biphenyl, cypermethrin, linuron, methomyl, oxadiazon, pendimethalin via consuming a large portion of spinach lettuce and watercress. Besides, the evaluated Cancer and non-cancer risk for acetamiprid, azoxystrobin, boscalid, carbendazim, chlorpyrifos, cypermethrin, imidacloprid, methomyl, myclobutanil, kresoxim-methyl, penconazole, tebuconazole, and pyrimethanil found in watercress, spinach, mallow, vine leaves, and lettuce do not pose a severe health risk for Saudi consumers. As part of future research, Saudi Arabian researchers can conduct a risk assessment and obtain accurate estimates by providing a database containing food consumption, large portions, and average weight for each specific population group. Local specifications must consider more pesticides to ensure compliance with the permissible limit on leafy vegetables and other crops.

Declaration of Interests

The authors declare that no competing interests exist in this manuscript. The views expressed in this paper are those of the author(s) and do not necessarily reflect those of the SFDA or its stakeholders. Guaranteeing the accuracy and the validity of the data is the sole responsibility of the research team.

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article.

Acknowledgments

This research was financially supported by the Saudi Food and Drug Authority (SFDA). The authors are grateful to the Research and Laboratories Sectorin SFDA for their keen interest in the study and instrumental support.

Author Contribution Statement

Dalal Alqahtani: Formal analysis, carried out the data analysis. Did the statistical analysis. Writing - original draft, wrote the manuscript; Mohammed Al-Mutairi: Formal analysis, Writing Review & Editing, carried out the data analysis, did the statistical analysis; Nasser Alrashed: Formal analysis, Writing - original draft, wrote the manuscript.; Rakan Alajmi: Formal analysis, carried out the data analysis, Review and Editing; Abdullah Alowaifeer: Formal analysis, carried out the data analysis.

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