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Review Article

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The concentration and human health risks attributed to pesticide residues in cucumber: A systematic review and meta-analysis

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Abstract

Background: Prolonged consumption of vegetables containing pesticide residues can pose a risk to the health of individuals over time.

Methods: This study aimed to retrieve the studies on the concentration of pesticides such as acetamiprid, chlorpyrifos, and diazinon in cucumber through a systematic review, and then, a meta-analysis focusing on specific subgroups. Finally, the hazard quotient (HQ) was used to assess the non-carcinogenic risk posed to consumers.

Results: The sequence of pesticides according to pooled (mean) concentration was acetamiprid (140.91 µg/kg) > diazinon (59.03 µg/kg) > chlorpyrifos (40.49 µg/kg). Also, the countries were sorted based on the pooled concentration of chlorpyrifos: Spain (180.00 µg/kg) > Egypt (124.90 µg/kg) > Kazakhstan (49.95 µg/kg) > Greece (20.50 µg/kg) > Saudi Arabia (20.00 µg/kg) > Jordan (3.54 µg/kg) > Iran (3.10 µg/kg). The order for diazinon and acetamiprid was Iran (43.20 µg/kg) > Saudi Arabia (33.00 µg/kg) > China (4.60 µg/kg) and Turkey (231.70 µg/kg) > Egypt (220 µg/kg) > Pakistan (100.00 µg/kg) > Kazakhstan (99.34 µg/kg), respectively.

Conclusion: The HQ of acetamiprid, chlorpyrifos, and diazinon was less than 1 for all countries; hence, the consumption of cucumbers containing these pesticides does not pose a non-carcinogenic risk.

Keywords: Agrochemical, Exposure, Meta-analysis, Pesticide, Risk assessment

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Introduction

In response to the growing global population, food producers must increase food production and minimize waste to ensure an adequate food supply (1,2). This is essential to meet the rising demand for food by scaling up production and increasing crop yield per unit of area (3,4). According to the United Nations, it is estimated that the world population will reach 9.8 billion by 2050 (5). The Food and Agriculture Organization (FAO) states that meeting the nutritional needs of the global population in 2050 would require increasing total food production by approximately 70% (6,7).

Agrochemicals, including fertilizers and pesticides, have become essential in modern agriculture for increasing yields with less effort. Additionally, these nutrients promote crop growth and soil health (8). About 33% of global crop productivity could be compromised by pests such as diseases, rodents, weeds, plant-feeding insects, and mites. Pesticides are the most common substances used to control these detrimental elements (9,10). They are biological and chemical substances extensively utilized in modern agriculture to enhance crop yields by safeguarding plants through methods such as deterring, incapacitating, eliminating, or discouraging pests (11,12).

Organophosphate pesticides (OPs) can have harmful impacts on human health. Approximately 0.1% of the pesticides applied reach the intended pests, while the rest are dispersed into water, soil, and food (13). The prevalence of pesticide poisoning among humans worldwide has risen significantly. In 1972, there were about 500 000 cases per year, which increased to approximately 25 million cases per year in 1990 (14). Pesticides pose significant risks to human health, affecting various bodily systems (12). They can disrupt metabolic homeostasis and with other variables have been associated with disturbances in the endocrine system, insulin resistance, nonalcoholic fatty liver disease, obesity, diabetes, blood cancer, and increased risks of lung and prostate cancer (15). Exposure to OPs encompasses more than just occupational contact, extending to contact through dust and aerosols, as well as the ingestion of contaminated food (16,17).

Food security is a significant public concern worldwide (18,19). The FAO defines food security as the physical, social, and economic access of all individuals to adequate, safe, and nutritious food at all times, ensuring a healthy and active life (20). The United States Environmental Protection Agency (USEPA) classifies the majority of OPs based on their toxicity levels for inhalation and oral exposure, using classes I to IV (21).

Vegetables and fruits are essential elements of diets promoted under the term "healthy lifestyle" because they offer vital nutrients, dietary fiber, and vitamins. According to the World Health Organization (WHO), vegetables and fruits typically account for approximately 30% of food consumption worldwide (22,23). The existence of organophosphate residues in vegetables and fruits could endanger consumer health, as these substances are a significant component of the human diet (24,25).

Cucumber (*Cucumis sativus* L.) is a commonly cultivated crop from the Cucurbitaceae family, grown in open fields and protected houses (26). It is a healthy fruit with numerous benefits, including maintaining blood pressure, regulating hydration, controlling blood sugar, aiding in weight loss, and promoting skin health and digestion. Cucumbers are high in water content, vitamins (K, C, A), and minerals (potassium, manganese, magnesium), and they also contain fiber. Additionally, they have hydrating, antimicrobial, and detoxifying properties, and may help prevent cancer and bone diseases (27,28).

To this end, several studies have been conducted globally to evaluate the presence of pesticide residues in various vegetables. For instance, in 2018, a total of 19 samples of cucumber and tomato were randomly collected from 14 greenhouse farms. The findings showed that diazinon, malathion, chlorpyrifos, ethephon, profenofos, and oxyfluorfen were detected in 94.7% of the samples. The residue levels in the cucumber samples varied between 0.05 and 167.19 mg/kg, while those in the tomato samples ranged from 2.55 to 136.87 mg/kg, all exceeding the maximum residue limits (MRLs) established by the Codex Alimentarius (29). In another study conducted in Iran, 64 samples of fresh cucumbers were analyzed for the presence of four pesticides (diazinon, imidacloprid, Pirimicarb, and acetamiprid). The cucumbers were randomly sampled 2, 5, 10, and 14 days after pesticide application. The results showed that acetamiprid and Pirimicarb had higher persistence in cucumbers compared to the other two pesticides. The lowest residue levels in cucumbers were detected 14 days after the application of acetamiprid (2.06 mg/kg) and pirimicarb (2.12 mg/kg). In contrast, the lowest residue levels of diazinon and imidacloprid were 0.24 and 1.16 mg/kg, respectively, within 14 days. All tested residues dissipated completely 21 days after application in cucumbers (30). Likewise, another investigation in Malaysia examined the possible presence of diazinon, chlorpyrifos, and dimethoate residues in cucumbers and tomatoes conveniently sampled from four food outlets within Taman University. The research found that there were no traces of diazinon, chlorpyrifos, and dimethoate residues in the cucumber and tomato samples collected from these permanent food outlets (31).

Despite existing concerns and evidence about the unprincipled use of pesticides in agriculture, the effects related to human health have not been comprehensively investigated so far. In the present study, cucumber was considered as a product that is consumed all over the world. This study is a systematic review and meta-analysis that addresses a significant gap in previous studies by conducting a thorough review and analysis of pesticide levels in cucumbers, aiming to understand their potential impact on human health. To achieve this, the study specifically focuses on examining the concentrations of chlorpyrifos, acetamiprid, and diazinon in cucumber, a widely used vegetable in diverse cuisines worldwide. By synthesizing data from various studies, this review takes a meticulous approach to evaluate the overall extent of pesticide contamination in cucumbers and understand the non-carcinogenic health risks associated with consuming them. The results of this investigation will greatly enhance our comprehension of the current state of pesticide residues in cucumbers. By illuminating this issue, the study will provide essential information that can be employed to develop efficient measures to reduce these risks and safeguard the food supply for consumers.

Materials and Methods

Search strategy

The literature search was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Figure 1) (32,33) through scientific databases such as PubMed, Web of Science, and Scopus from January 1, 2010 to April 1, 2022. The search was based on the following terms: "Cucumber OR "Cucumis sativus" OR C. sativus" AND "pesticide OR acetamiprid OR chlorpyrifos OR diazinon".

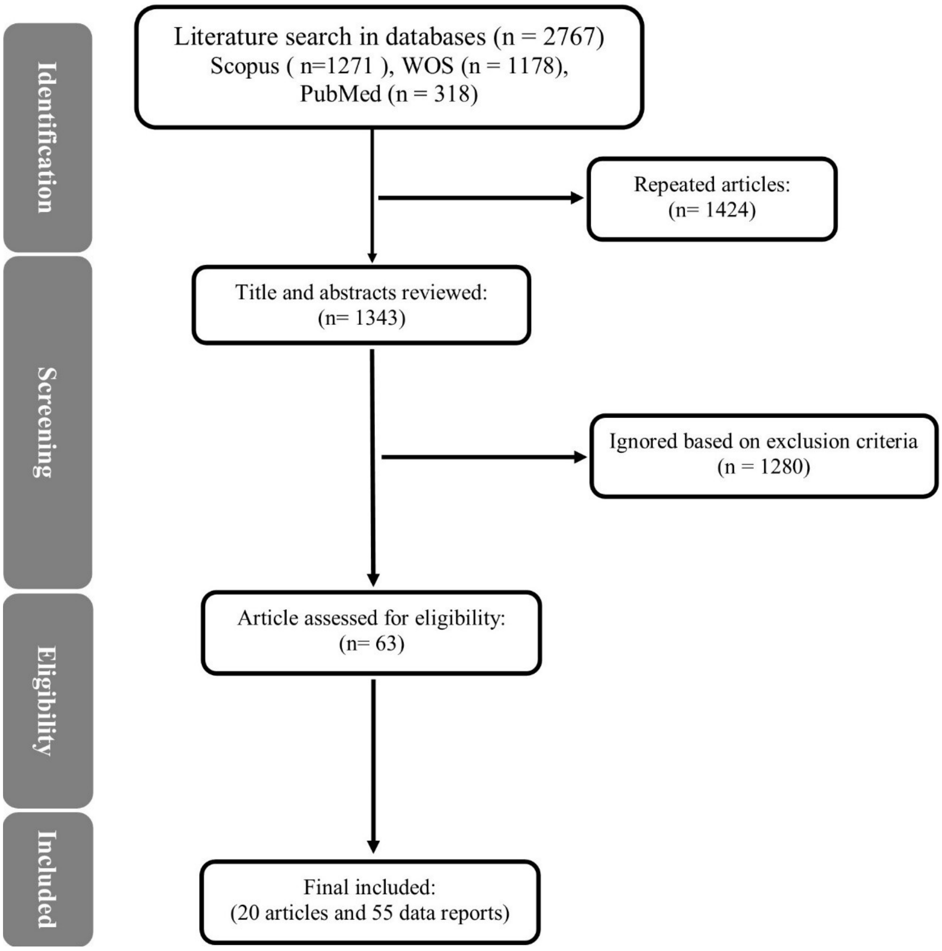


Figure 1. The selection process of articles based on the PRISMA protocol

Disagreements in the selection of articles were resolved through the final comment of the correspondence (34).

Inclusion and exclusion criteria

Among the mentioned databases, the studies that evaluated pesticide levels in vegetables were included based on the following criteria: The articles were published in English, the articles that their full text was accessible, the original studies distinctly monitored the concentration of chlorpyrifos and diazinon in cucumber, and those that reported statistical details (mean, standard deviation [SD], and/or standard error [SE]) about the pesticides. In addition, the exclusion criteria were: Theses, clinical studies, abstracts, books, case series, case reports, conference papers, review studies, and letters to the editor; the lab-studies that estimated the fate and behavior of pesticides in water-soil-plant, and finally, lab-studies that evaluated the analytical methods.

Data extraction

In this research, the collected data included the author(s) name, publication year, place (country) of sampling, type of pesticide, statistical details (mean, SD/ or SE, and sample size), and title of the study. After the extraction of data, the statistical details about the concentration of the chemicals were unified as mg/kg (wet-weight) of the vegetable.

Statistical and meta-analysis of data

The meta-analysis of the extracted data was conducted using STATA version 14.0 (Stata Corp, College Station, TX). After unifying the data units, mean concentration, and SE were considered for the analysis. SE was calculated using SD and sample size (N) according to Eq. 1(35).

$$\mathrm{SE} = \frac{SD}{\sqrt{N}} \tag{1}$$

The subgroup analysis was conducted separately according to the sampling country. Heterogeneity, as an index describing the properties of a dataset, was assessed using I^2. According to Cochrane recommendations, I^2 higher than 50% indicates substantial heterogeneity. Since the dataset obtained in this study showed heterogeneity greater than 90%, an analysis was conducted using a random effects model (36).

Health risk assessment

The estimation of exposure among the investigated countries, as the initial stage in evaluating health risk was conducted by Eq. (2) (37).

$$EDI = \frac{Cm \times IR \times EF \times ED}{BW \times ATn} \quad (2)$$

Here, EDI represents the estimated daily intake (mg/kg.day), C_m is the concentration of pesticides (mg/kg-wet weight), IR is the ingestion rate (g/n-d), EF is the exposure frequency (350 day/year), ED is the exposure duration (children = 6 years and adults = 30 years), BW is body weight (children = 15 kg and adults = 70 kg), and ATn (365 × ED) is average time exposure (children = 2190 days and adults = 10 950 days). The ingestion rate for cucumber was assumed to be 10% of the human vegetable ingestion rate obtained from the Food and Agriculture Organization of the United Nations (FAO) statistics (38).

To evaluate the hazard quotient (HQ) in association with non-carcinogenic risk (n-CR), Eq. (3) was used. Where, RfD implies reference dose, which is considered to be 0.001, 0.0007, and 0.07 for chlorpyrifos, diazinon, and acetamiprid, respectively (39,40). The cumulative risk associated with the simultaneous ingestion of all chemicals is calculated via Eq. (4) (41).

$$\mathrm{HQ} = \frac{EDI}{RfD} \quad (3)$$

$$THQ = \sum_{i=1}^{n} HQ_i \quad (4)$$

Results

Selection process and characteristics of studies

The present study primarily focused on the systematic review and meta-analysis of the concentration of acetamiprid, chlorpyrifos, and diazinon in cucumbers. This involved searching through the databases Scopus, Web of Science, and PubMed, resulting in the retrieval of 2767 articles for analysis. After the removal of 1424 duplicate papers, the titles and abstracts of the selected studies were screened for eligibility, leading to the exclusion of 1280 articles that did not meet the criteria. Ultimately, 20 articles were included that fulfilled all required criteria (Figure 1).

Of the articles finally selected, which were conducted in 11 countries (Turkey, Egypt, Kazakhstan, Pakistan, Greece, Jordan, Iran, Saudi Arabia, Kazakhstan, Spain, and China), the ranking of years based on the number of studies conducted in was as follows: 2014 > 2016 > 2020 ≈ 2021 (Figure 2-a). Most of these studies focused on monitoring chlorpyrifos (41%) ≈ diazinon (41%) compared to acetamiprid (18%) (Figure 2-b), which can be due to the higher consumption of Chlorpyrifos and Diazinon in agriculture and household pest control (42,43).

It should be noted that the usage amounts of these pesticides may vary depending on factors such as crop types, pest infestations, and regional preferences, and can differ from one country to another (44). The characteristics of the included articles are presented in Table 1.

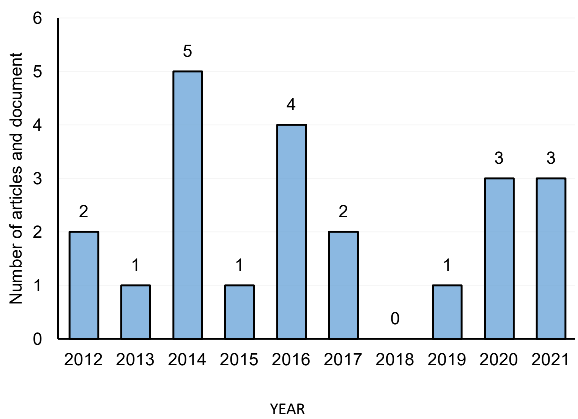
Meta-analysis concentration of pesticides

The concentration of pesticides

According to the results indicated in Tables 2-4, the overall ranking of countries based on the concentration of chlorpyrifos was as follows: Spain (180.00 µg/kg) > Egypt (124.90 µg/kg) > Kazakhstan (49.95 µg/kg) > Greece (20.50 µg/kg) > Saudi Arabia (20.00 µg/kg) > Jordan (3.54 µg/kg) > Iran (3.10 µg/kg). The order for diazinon and acetamiprid was Iran (43.20 µg/kg) > Saudi Arabia (33.00 µg/kg) > China (4.60 µg/kg) and Turkey (231.70 µg/kg) > Egypt (220 µg/kg) > Pakistan (100.00 µg/kg) > Kazakhstan (99.34 µg/kg), respectively. The obtained results from the present study, reported in Tables 2-4, showed the relative ranking of pesticides based on their concentrations in cucumber as follows: Acetamiprid (140.91µg/kg) > Diazinon (59.03 µg/kg) > Chlorpyrifos (40.49 µg/kg).

Health risk assessment

According to the results reported in Table 5, the HQ



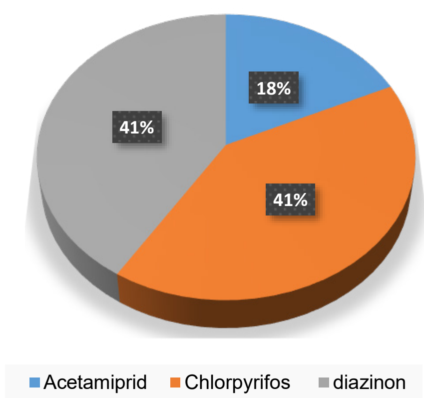


Figure 2. Statistical information about the included articles: (a) the number of selected articles reported per year, (b) the contribution of studies by the type of pesticide

Table 1. The characteristics of the included articles

Reference	Author	Year	Country	Unit	Pesticides	Sample Size	Mean	SD	SE
(45)	Yu et al	2016	China	µg/kg	Diazinon	31	4.600	0.506	0.091
(46)	Vlassi et al	2020	Greece	µg/kg	Chlorpyrifos	10	20.500	2.255	0.713
(47)	Ibrahim et al	2019	Jordan	µg/kg	Chlorpyrifos	5	7.000	30.000	13.416
(47)	Ibrahim et al	2019	Jordan	µg/kg	Chlorpyrifos	5	3.536	0.389	0.174
(47)	Ibrahim et al	2019	Jordan	µg/kg	Chlorpyrifos	5	3.536	0.389	0.174
(47)	Ibrahim et al	2019	Jordan	µg/kg	Chlorpyrifos	5	3.536	0.389	0.174
(47)	Ibrahim et al	2019	Jordan	µg/kg	Chlorpyrifos	5	3.536	0.389	0.174
(48)	Sungur & Tunur	2012	Turkey	µg/kg	Acetamiprid	10	437.000	20.000	6.325
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	12	13.300	0.720	0.208
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	12	10.420	0.760	0.219
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	10	9.260	1.070	0.338
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	6	17.200	3.500	1.429
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	12	13.770	2.100	0.606
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	5	9.550	0.540	0.241
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	6	10.040	0.980	0.400
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	11	9.840	1.210	0.365
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	5	9.210	1.130	0.505
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	10	18.400	3.340	1.056
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	16	11.540	2.070	0.518
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	7	10.870	1.070	0.404
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	5	12.090	1.310	0.586
(49)	Shokrzadeh et al	2017	Iran	µg/kg	Diazinon	5	9.200	1.103	0.493
(50)	Shalaby et al	2021	Egypt	µg/kg	Acetamiprid	16	220.000	24.200	6.050
(50)	Shalaby et al	2021	Egypt	µg/kg	Chlorpyrifos	16	220.000	24.200	6.050
(51)	Nasiri et al	2016	Iran	µg/kg	Chloropyrifos	43	0.097	0.001	0.000
(52)	Mosleh et al	2014	Saudi Arabia	µg/kg	Chlorpyrifos	5	20.000	2.000	0.894
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Acetamiprid	19	250.000	27.500	6.309
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Acetamiprid	19	10.000	1.100	0.252
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Acetamiprid	19	100.000	11.000	2.524
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Acetamiprid	19	10.000	1.100	0.252
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Acetamiprid	19	150.000	16.500	3.785
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Chlorpyrifos	19	70.000	7.700	1.767
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Chlorpyrifos	19	30.000	3.300	0.757
(53)	Lozowicka et al	2015	Kazakhstan	µg/kg	Chlorpyrifos	19	50.000	5.500	1.262
(54)	Jamshidi et al	2016	Iran	µg/kg	Diazinon	106	4850.000	7440.000	722.637
(54)	Jamshidi et al	2016	Iran	µg/kg	Diazinon	21	10.000	30.000	6.547
(54)	Jamshidi et al	2016	Iran	µg/kg	Diazinon	85	6560.000	8320.000	902.431
(55)	Ganjeizadeh Rohani et al	2014	Iran	µg/kg	Diazinon	17	264.000	29.040	7.043
(55)	Ganjeizadeh Rohani et al	2014	Iran	µg/kg	Diazinon	17	832.000	91.520	22.197
(55)	Ganjeizadeh Rohani et al	2014	Iran	µg/kg	Diazinon	17	1113.000	122.430	29.694
(55)	Ganjeizadeh Rohani et al	2014	Iran	µg/kg	Diazinon	17	173.000	19.030	4.615
(55)	Ganjeizadeh Rohani et al	2014	Iran	µg/kg	Diazinon	17	526.000	57.860	14.033
(55)	Ganjeizadeh Rohani et al	2014	Iran	µg/kg	Diazinon	17	582.000	64.020	15.527
(56)	EL-Saeid & Selim	2013	Saudi Arabia	µg/kg	Diazinon	1057	33.000	3.630	0.112
(57)	Davoodi et al	2014	Iran	µg/kg	Diazinon	10	264.000	295.000	93.287
(58)	Darvishnejad et al	2020	Iran	µg/kg	Chlorpyrifos	17	3.100	0.341	0.083
(58)	Darvishnejad et al	2020	Iran	µg/kg	Diazinon	17	3.400	0.374	0.091

Table 1. Continued.

Reference	Author	Year	Country	Unit	Pesticides	Sample Size	Mean	SD	SE
(59)	Bazmandegan-Shamili et al	2017	Iran	µg/kg	Diazinon	17	1.510	0.060	0.015
(60)	Bakırcı et al	2014	Turkey	µg/kg	Acetamiprid	69	26.500	2.915	0.351
(61)	Bagheri et al	2012	Iran	µg/kg	Diazinon	7	55.000	5.100	1.928
(61)	Bagheri et al	2012	Iran	µg/kg	Diazinon	7	82.000	6.900	2.608
(62)	Ahmed et al	2014	Egypt	µg/kg	Chlorpyrifos	17	30.000	2.000	0.485
(63)	Quijano et al	2016	Spain	µg/kg	Chlorpyrifos	25	180.000	19.800	3.960
(64)	Siddique et al	2021	Pakistan	µg/kg	Acetamiprid	17	100.000	29.000	7.034

Table 2. Meta-analysis concentration of chlorpyrifos in cucumber (µg/kg)

Study	Number of studies	ES[a]	Lower	Upper	Weight (%)	Heterogeneity Statistic	Degrees of freedom	*P* value	I²
Greece	1	20.500	19.103	21.897	7.93	0.00	0	.	.%
Jordan	1	3.536	3.366	3.707	33.88	0.07	4	0.999	0.0%
Egypt	2	124.904	0	311.101	12.78	979.97	1	0.000	99.9%
Iran	2	3.100	2.937	3.263	8.00	0.00	0	.	.%
Saudi Arabia	1	20.000	18.248	21.752	7.89	0.00	0	.	.%
Kazakhstan	1	49.955	27.867	72.044	23.28	524.64	2	0.000	99.6%
Spain	1	180.000	172.239	187.761	6.23	0.00	0	.	.%
Overall	9	40.489	36.368	44.610	100.00	11004.82	13	0.000	99.9%

[a] Effect size: Weighted average.

Table 3. Meta-analysis concentration of diazinon in cucumber (µg/kg)

Study	Number of studies	ES[a]	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*P* value	I²
China	1	4.600	4.422	4.778	4.31	0.00	0	.	.%
Iran	7	43.204	40.238	46.170	91.38	20246.48	27	0.000	99.9%
Saudi Arabia	1	33.000	32.780	33.220	4.31	0.00	0	.	.%
Overall	9	59.030	54.586	63.473	100.00	97222.10	29	0.000	100.0%

[a] Effect size: Weighted average.

Table 4. Meta-analysis concentration of acetamiprid in cucumber (µg/kg)

Study	Number of studies	ES[a]	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*P* value	I²
Turkey	2	231.701	0	633.985	22.26	4199.23	1	0	100.00%
Egypt	1	220	208.142	231.858	10.72	0	0	.	.%
Kazakhstan	1	99.342	85.132	113.552	56.58	4058.48	4	0	99.90%
Pakistan	1	100	86.214	113.786	10.44	0	0	.	.%
Overall	5	140.912	126.899	154.926	100	11392.4	8	0	99.90%

[a] Effect size: Weighted average.

values of all three types of pesticides for both children and adults were less than 1 in all countries, implying no appreciable non-cancer health risk.

Discussion

The consumption of pesticides varies across countries due to a range of factors, including agricultural methods, the social processes of pesticide application, economic factors, food security regulations, and politics (65,66). Although some developed countries have made noticeable progress in decreasing pesticide use intensity, there has been a significant increase in pesticide usage in some developing countries. This has resulted in an uneven geographical distribution of pesticide consumption (67). However, the reasons for the high consumption of pesticides in countries with the highest consumption levels have been investigated.

The California red scale (*Aonidiella aurantii*) is the main citrus pest in Spain (68). Chlorpyrifos, an insecticide, has been the foundation for managing red-scale in Spain for

Table 5. Non-carcinogenic HQ risk in adults and children due to the ingestion of cucumbers containing pesticides

Age group	Country	Chlorpyrifos	Diazinon	Acetamiprid
Adult	China	-	0.008	-
	Greece	0.012	-	-
	Jordan	0.001	-	-
	Egypt	0.038	-	0.001
	Iran	0.001	0.019	-
	Saudi Arabia	0.003	0.007	-
	Kazakhstan	0.036	-	0.001
	Pakistan			0.000
	Spain	0.034	-	-
	Turkey			0.001
Child	China	-	0.037	-
	Greece	0.054	-	-
	Jordan	0.004	-	-
	Egypt	0.176	-	0.004
	Iran	0.005	0.089	-
	Saudi Arabia	0.014	0.032	-
	Kazakhstan	0.166	-	0.004
	Pakistan			0.000
	Spain	0.160	-	-
	Turkey			0.006

many years (69). This highly effective active ingredient is fast-acting, providing a quick 'knock-down' effect on pests (70). Due to the lack of an alternative to chlorpyrifos with this activity profile, its availability and consumption are very high in Spain, leading to increased usage across all types of crops (71). For example, chlorpyrifos was detected in 22% of samples such as apples, carrots, bananas, citrus fruits, grapes, lettuce, peaches, pears, potatoes, tomatoes, and cucumbers in Valencia (Spain) (63).

There are different conditions in Egypt due to the country's heavy reliance on agriculture and the use of pesticides to protect crops from pests and diseases (72). In this area, improper use of agricultural pesticides has increased the pollution of the Nile River, the main source of irrigation (73). As a result, irrigation with this contaminated water can lead to contamination of soil and agricultural products, as reported by many Egyptian studies (74-76). Among the different pesticides used in Egypt, Chlorpyrifos is one of the most frequently utilized OPs (77,78). It is consumed at approximately 1280 tons each year, according to statistics from the Agricultural Pesticides Committee, Ministry of Agriculture & Land Reclamation (79). Similar studies in local markets of Egypt have shown that Chlorpyrifos is commonly found alongside at least one other compound in soil and crop samples from this area, and residues of this pesticide were detected in three types of crops (74). Although its application is government-regulated, the precise dates of application differ among fields depending on local insect infestations (80). Ibrahim et al, mentioned that increasing awareness among Egyptian farmers to reduce pesticide usage should be achieved through training on reasonable usage, following instructions on information labels, and complying with estimated safety periods (81).

Diazinon, an organophosphorus pesticide, is extensively used to control aphids, caterpillars, moths, butterflies, various worms, locusts, grasshoppers, and scales in pastures, orchards, vegetables, and field crops due to its high effectiveness and medium-low toxicity (82,83).

It is widely used in Iranian agriculture due to its low cost and effectiveness (84,85). According to a study (86) in Iran during 2012–2014, approximately 14 000 tons of pesticides were used, with Diazinon making up 5% of the total amount. Although the majority of Diazinon's use in Iran is related to the northern regions and agricultural lands (87), some studies indicate its application in other areas as well. For example, Ebrahimzadeh et al study., conducted in Sistan and Baluchistan province (south-east of Iran), Diazinon is extensively utilized for agricultural purposes (88). The researchers mentioned that due to the increased use of Diazinon in spring, the season marking the beginning of crop cultivation, and the higher rainfall in this season, there is a higher probability of Diazinon transfer to the soil, and ultimately, more absorption in crops (89). Furthermore, the lack of a modern irrigation system in Iran has been identified as another factor contributing to the pesticide's transfer to water sources. Creating a network that integrates traditional knowledge of pests with scientific pesticide knowledge, sharing innovations that mitigate the adverse effects of pesticides, providing farmers with information that encourages changes in harmful pesticide practices, establishing close communication between agricultural experts and farmers, and updating the technical knowledge of agricultural experts in the management and usage of pesticides are the most important policy measures to improve the effective use of pesticides (90).

In Saudi Arabia, along with the expansion of agricultural land, the consumption of pesticides has also increased (91). This country was among the early adopters of the Stockholm Convention in 2002. However, due to the lack of data on persistent organic pollutants, it has not fully ratified the agreement (92). Meanwhile, Diazinon was the most commonly found pesticide in this area (93). Case in point, in a study conducted in the Asir Region of Saudi Arabia, 41.7% of Cucumber samples had detectable pesticide residues above the MRLs (94). The increasing pest attacks on important crops have been a significant issue in recent years (95). Additionally, climate change has exacerbated the incidence and spread of plant pests and diseases in this region, making crops more susceptible to various pests and diseases, thereby impacting crop productivity in recent years (96). This rise in pest populations necessitates the implementation of control and monitoring programs (97). Reducing government involvement in distribution to decrease the need for maintaining large pesticide stocks, encouraging private sector participation, controlling prices, reducing subsidies or preferential tariffs on pesticides, limiting pesticide stock, and establishing strict regulation and control systems can help prevent the residues of pesticides in Saudi Arabia.

Acetamiprid is a neonicotinoid insecticide widely used on a variety of crops to control insect pests such as aphids, whiteflies, and beetles (98). It acts as a nicotinic acetylcholine receptor (nAChR) agonist, making it highly efficient in pest control (99). Turkey applies 33 million kg of pesticides annually, with 29% consisting of insecticides like Acetamiprid (100). The most important reason for the widespread use of Acetamiprid in Turkish agriculture is its effectiveness in controlling insects such as aphids, which can damage leafy plants, resulting in residues that can pose a threat to human health (101). The use of Acetamiprid in Turkey is regulated by the Turkish Food Codex and the European Union's maximum acceptable limits (102). However, there have been instances where residues of Acetamiprid were detected in cucumber samples at concentrations exceeding the maximum acceptable limit (103). In a study (104) conducted in supermarkets, bazaars, and greengrocer shops across Turkey, about 30.77% of the samples contained Acetamiprid residue above the MRL value (105,106). It was mentioned that some of the reasons for the high use of this pesticide in Turkey are its effectiveness in controlling pests, availability, and regulatory compliance, making it a convenient choice for farmers and agricultural workers. Meanwhile, over 50% of Turkish farmers and agricultural workers believe that pesticides are not harmful to them. Therefore, it is essential for governmental agencies, as well as the private sector, to address these issues through educational strategies (107).

According to the literature, the most important actions to decrease pesticide usage, improve their management, and subsequently, reduce their harmful effects in various countries include increasing awareness and training, researching and developing alternative pest management techniques and non-chemical methods, and implementing policies and regulations that promote sustainable and reduced pesticide use. It should be noted that the effectiveness of methods to reduce pesticide use varies across countries due to a complex interplay of agricultural, regulatory, economic, cultural, and technological factors.

The concentration of these pesticides in cucumbers can be influenced by various factors, such as surface evaporation, which depends on temperature conditions, as well as chemical or biochemical decomposition, metabolism, and photolysis (108). These results clearly show that Acetamiprid is used more frequently in cucumbers compared with the other two pesticides. One reason may be related to the high availability, and subsequently, improper use or overuse of it (109). As mentioned earlier, Acetamiprid, a neonicotinoid insecticide, poses lower risks to mammals and the environment in comparison with organophosphate insecticides like diazinon and chlorpyrifos (98,110). Previous studies have also demonstrated effective control and management of Acetamiprid residues in cucumbers, making it a suitable option for pest control in cucumber farming (111). In addition, it has a shorter pre-harvest interval, allowing it to be applied closer to the harvest (112).

On the other hand, this may indicate a greater persistence of this pesticide in cucumbers compared to the other two pesticides, which is consistent with the results of similar studies (108,113). Based on the searches conducted in the present study, there is no specific information on why Acetamiprid may be more persistent in cucumbers. However, the persistence of Acetamiprid in cucumbers could be influenced by several factors, such as its chemical properties, method of application, and interactions with cucumber plants (114). Acetamiprid is highly permeable and can be quickly absorbed and transmitted to all parts of the crop, contributing to its persistence (98). Additionally, the specific metabolic and degradation pathways of this pesticide and its interactions with plant physiology may also play an important role in its persistence (115). However, additional or specialized studies may be needed to fully understand the factors contributing to the persistence of Acetamiprid in plants like cucumber.

Generally, as shown in Figure 3, pesticides can be absorbed by plants through the leaves and roots (116).

The absorption of pesticides by plant roots mainly occurs through the transepithelial absorption process (117). Transepithelial absorption refers to the movement of pesticides through apoplastic and symplastic pathways, in which substances move through the cytoplasm or cell walls of the root's epithelial cells, respectively (118). These pathways play a vital role in the absorption and movement of pesticides within plants, influencing their distribution and potential effects on plant metabolism and growth (119).

In the absorption of pesticides from leaves, simple diffusion has a critical role (120). When a drop of pesticide falls on a leaf, absorption begins at the surface. For the pesticide to reach the cytoplasm, it must move through the cuticle, the cell wall, and finally, the cell membrane. Accordingly, the leaf surface area is a significant factor in the amount of pesticide absorption in plants (121).

To evaluate the potential non-cancer health hazards associated with exposure to pesticides in cucumbers, HQ was calculated (122). An HQ $\leq$ 1 suggests that adverse effects are unlikely to occur, indicating a negligible

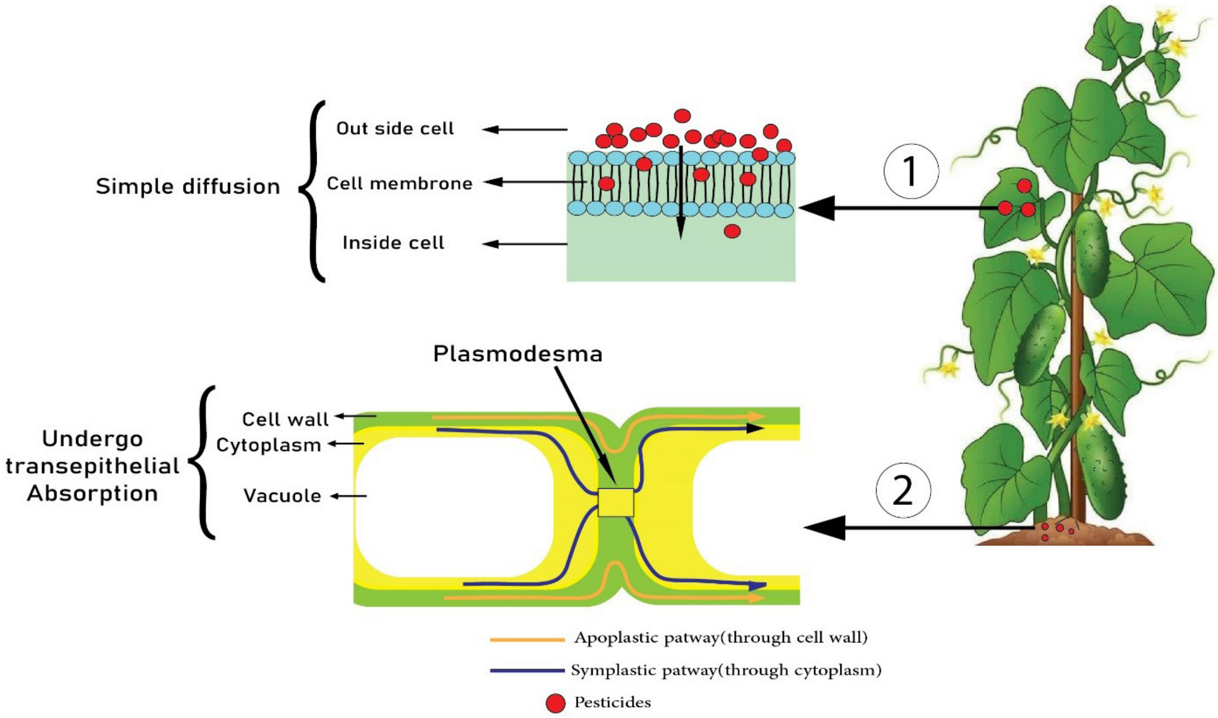


Figure 3. Absorption pathways of pesticides in cucumber

level of hazard. In contrast, HQs ≥ 1 indicate a potential for adverse effects, and further toxicological analysis is recommended (123). According to the results reported in Table 5, the HQ values of all three types of pesticides for both children and adults were less than 1 in all countries, implying no appreciable non-cancer health risk (124,125). However, it is important to consider the following points:

- Other exposure routes, such as inhalation and skin contact, may still be present and cannot be disregarded in a non-cancer risk assessment (126,127).
- The per capita consumption of cucumber differs notably across various countries, which can impact human health due to pesticide exposure. High per capita consumption of cucumber increases exposure, and therefore, enhances absorption in the body (128).
- Although all detected pesticides had no potential health risk individually, it should be noted that pesticide exposure through cucumber consumption, due to the cucumber consumption as uncooked foods, can be a serious concern in the long term if they are unwashed (129, 130).
- According to the "cocktail effect" phenomenon, when pesticides are combined in food, they can have a more significant impact on human health than when they are used individually. Therefore, it is essential to conduct comprehensive studies on the combined effects of pesticides rather than focusing solely on the individual effects of each pesticide (131,132).

Furthermore, the results from this study suggest that children face comparatively greater risks than adults. The increased risk for children could be due to their higher food intake per kilogram of body weight (133), as reported in similar previous studies (134,135).

According to the findings, it is concluded that although the HQ ratio was less than one in all countries, the possible consequences of excess exposure to pesticides deserve further attention and special measures need to be taken to protect children, the most vulnerable population, from pesticide toxicity. The presence of pesticide residues in cucumbers is a critical public health concern that requires ongoing monitoring and innovative detection methods. While current assessments indicate that risks are generally low, continuous vigilance is necessary to mitigate potential health impacts associated with long-term exposure to these chemicals.

One of the most important limitations of this study is the difference in per capita cucumber consumption across different countries, which is influenced by cultural preferences, dietary habits, and economic factors. This variation can impact the calculated risk values related to health and nutrition. Understanding these differences is crucial for health policymakers and researchers when assessing dietary risks and planning interventions tailored to specific populations. It would be more effective to calculate the levels of risk for each country based on its per capita consumption of cucumbers. Also, the amount of agricultural pesticide use varies among countries, with some having implemented strict laws regarding pesticide application in agriculture. This issue should also be taken into consideration when assessing the health risks of pesticides.

Conclusion

In the present report, the pooled concentrations of the investigated chemicals (acetamiprid, chlorpyrifos, and diazinon) in cucumbers were assessed via meta-analysis. The next step involved estimating the corresponding n-CR through the consumption of the vegetable. The analyzed data retrieved from 20 papers indicated pooled concentrations of 140.91, 59.03, and 40.49 µg/kg for acetamiprid, diazinon, and chlorpyrifos, respectively. Depending on some factors such as culture, agricultural methods, pesticide application, economic factors, food security regulations, and politics, the pooled concentrations were obtained differently among the countries. The corresponding health risk calculated using the EPA method for all chemicals indicated an HQ lower than 1, which interprets safe consumption. Although the results indicate safe consumption, considering that cucumber is a fixed product in the diet, its regular consumption may still pose health risks. The implementation of public awareness campaigns, along with legal regulations (e.g., the EU's Farm to Fork strategy) could significantly reduce the health impacts associated with pesticide use. Mitigating the human health impacts of agricultural pesticide use worldwide could be achieved by developing national and international plans for the sustainable use of pesticides, with an emphasis on the gradual elimination of hazardous pesticides, providing low-risk alternatives for high-risk crops, and strengthening periodic training to improve pesticide user performance.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical issues

This study was approved by the Ethics Committee of the Student Research Committee at Shahid Beheshti University of Medical Sciences.

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