

Risk Analysis of Exposure to Chlorpyrifos and Diazinon from Greenhouse-Grown Tomatoes during Pre-Harvest Interval and Post-Harvest Processing

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ABSTRACT

This study aimed to investigate the residue levels and dissipation rates of chlorpyrifos, diazinon, and their oxon derivatives in greenhouse-grown tomatoes and to evaluate the acute and chronic Hazard Quotients (HQ) for consumption of these products. The quantification analyses of chlorpyrifos and diazinon and their degradation products were performed using Gas Chromatography Coupled with Mass Spectrometry (GC-MS/MS). The Monte Carlo simulation technique was used to evaluate the variability and uncertainty of the data and to achieve more accurate results in the health risk assessment process. The chronic HQ values of chlorpyrifos and diazinon residues ranged from 0.24 to 0.85 and 0.06 to 1.09 for adults, 0.45 to 1.34 and 0.12 to 1.66 for adolescents, and 0.71 to 1.80 and 0.21 to 3.78 for children, respectively. After five days of storage in room and refrigerator temperatures, the HQ values of diazinon and chlorpyrifos were higher than the acceptable limits. According to the Monte Carlo simulation, the HQ and the estimated daily intake (EDI) values were more affected by the consumption rate followed by pesticide concentration and body weight. Therefore, due to the high frequency of tomato consumption, it is necessary to reduce the concentration of pesticides in this product in order to reduce human health risk.

Keywords: Chlorpyrifos oxon, Chronic hazard quotient, Monte Carlo analysis, Organophosphorus pesticides.

INTRODUCTION

Organophosphorus pesticides are extensively used in agriculture to control pests and grow crops, accounting for an estimated 38% of the total pesticide consumption in the world (Dar *et al.*, 2020). However, the incorrect application of these chemicals on food crops can lead to unacceptable residue levels in foodstuff even after post-harvest treatment (Zezelew *et al.*, 2018). It is assumed that dietary exposure to pesticide residues could be five times higher than the other ways including air and

drinking water (Juraske *et al.*, 2009). Pesticides cause several adverse human health effects such as carcinogenicity, neurotoxicity, genotoxicity, mutagenicity, endocrine disruption, cytogenetic damage, reproductive toxicity, and immune disorders (Siddoo-Atwal, 2019).

Diazinon and chlorpyrifos are the two most frequently used organophosphorus insecticides. The World Health Organization (WHO) considers diazinon and chlorpyrifos as class II, or moderately hazardous, based on their acute health effects. Their lowest doses that cause toxic effects (TDLO) are

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214 and 300 mg kg⁻¹, respectively (Soleimani *et al.*, 2019; Mulla *et al.*, 2020). The Maximum Residual Limits (MRLs) of pesticides in food commodities depend on the type of food and pesticide. The Codex MRLs of diazinon and chlorpyrifos range from 0.01 to 5 mg L⁻¹ and 0.01 to 20 mg L⁻¹, respectively (Ingenbleek *et al.*, 2019).

Previous studies have shown the positive correlation of diazinon with Non-Hodgkin Lymphoma (NHL), lung cancer, and chromosomal damage. Accordingly, it has been classified as “probably carcinogenic to humans” (Group 2A) (Fritschi *et al.*, 2015). Neurotoxicity is the main toxicity caused by chlorpyrifos. It has been reported that chlorpyrifos is associated with immunological abnormalities, Parkinson’s disease, and multiple chemical sensitivity. In addition, it induces cell death at a very low dose in a human monocyte cell line (Rauh, 2018; Perez and Arboleda, 2016).

Among the agricultural crops, tomato is considered as the second most consumed product in the world and its production has increased in recent years. In addition, the consumption of tomato paste ranks first among the canned agricultural products (Szabo *et al.*, 2018).

The pesticides used in agricultural crops can be changed and transformed during growth and post-harvest processing. The removal of pesticides in the field and after harvest depends on various factors such as the plant species, chemical formulation, physicochemical properties of the compound, reaction time, and environmental conditions (Albaseer, 2019).

Organophosphate pesticides generally turn into active metabolites (oxons), specific inactive metabolites, and general inactive metabolites (dialkylphosphates) through various phenomena (Kaur *et al.*, 2017).

Many regulatory authorities have established indicators for dietary risk assessment. The human health risk assessment is described by the environmental protection agency (EPA) as the process used for the estimation of the health impact of human exposure to

environmental contaminants and hazardous agents (Neris *et al.*, 2019).

As a dietary risk assessment indicator, MRL is the highest level of a pesticide residue that is legally tolerated in food, according to good agricultural practices. However, this index is not a toxicological limit and does not represent the maximum amount of the compounds that can be harmful to the consumer’s health (Li, 2018). Therefore, besides measuring MRL, it is essential that the other dietary standards such as the estimated daily intake, Lifetime Cancer Risk (LCR), and Hazard Quotient (HQ) be evaluated (Låg *et al.*, 2019; Shokoohi *et al.*, 2019).

In spite of the fact that pesticides are widely used in agricultural production, less information is known about the fate and residual behavior of the pesticides and their active metabolites during pre-harvest condition and post-harvest treatments. Although some researchers have studied the occurrence of pesticides residues in raw crops, few studies have focused on their behavior caused by household processing (Mebdoua and Ounane, 2019; Matthews, 2019; Philippe *et al.*, 2020). Thus, the current study aimed to investigate the residues levels and dissipation rates of chlorpyrifos, diazinon, and their oxon derivatives in tomatoes during pre-harvest interval and post-harvest household processing and to estimate the chronic and acute hazard quotients for the consumption of these products.

MATERIALS AND METHODS

Study Area and Sampling

The study area was Hamadan Province, which is located in the west of Iran and has a cold semi-arid. The experiments were conducted from the beginning of November to the end of December, 2019. The field trials were performed on experimental plots of tomato plants. Two treatments with chlorpyrifos (40.8% EC) and diazinon (60%

EC) were applied under greenhouse condition at the recommended dosages of 2/1000 (0.2% v/v) and 1/1000 (0.1% v/v), respectively. The tomato samples were randomly picked 2 hours, 1, 2, 3, 5, 10, and 21 days after pesticide application. After harvest, the tomato samples were transported to the laboratory for further analyses.

In addition, to investigate the dissipation pattern of the pesticides for the post-harvested tomatoes, 2 hours after spraying at the greenhouse, the harvested samples were collected separately and stored in the laboratory for different analyses. The tomato samples were analyzed for diazinon, chlorpyrifos, and their oxon derivatives at room temperature on days 1, 2, 3, and 5, at refrigerator temperature on days 1, 3, 5, and 7, and at boiling temperature after 5 minutes, 30 minutes, 45 minutes, 1 hour, and 2 hours. The total number of samples analyzed was 72, with 51 samples for household processing and 21 samples for field treatment. All experiments were performed in triplicate and repeated at least three times. The average temperatures of the household conditions (including storage at room and refrigerator temperatures and cooking) and field condition were 25 ± 1.4 , 4 ± 1 , 100 and 40.8 ± 2.9 °C, respectively.

Reagents and Materials

Diazinon (98.5%) and chlorpyrifos (99.0%) were purchased from Sigma-Aldrich. Diazoxon (97.7%) was provided by Toronto Research Chemicals (Toronto, Canada). Chlorpyrifos oxon (97.9%) was obtained from Dr. Ehrenstorfer (Augsburg, Germany). Trisodium citrate dehydrate, disodium hydrogen citrate, sodium chloride, magnesium sulfate, Primary-Secondary Amine (PSA), formic acid, acetonitrile, ethyl acetate, methane, and TPM (triphenylmethane) were analytical and HPLC grade and were acquired from Sigma-Aldrich (Switzerland).

Sample Pretreatment and Analysis

Extraction of the samples was done by a modified QuEChERS method (Mahdavi *et al.*, 2018). Four-hundred g of the tomato samples were thoroughly blended to obtain a homogeneous sample. Then, 10 g of the homogeneous tomato samples were placed in a 50 mL centrifuge tube and then 40 μ L TPM as the internal standard and 10 mL acetonitrile were added to them. The mixtures were shaken vigorously for 1 min. Then, 1 g trisodium citrate dehydrate, 1 g sodium chloride, and 0.5 g disodium hydrogen citrates were added to them and immediately shaken intensely for 1 minute. Afterwards, the mixtures were centrifuged for 10 min at 4,500 rpm at -2°C. The 3 mL aliquot was transferred to a centrifuge tube containing 4 g of dehydrated MgSO₄. The shaking step was repeated. The upper layer of the sample was transferred to a 15 mL polypropylene tube containing 150 mg anhydrous MgSO₄ and 25 mg Primary Secondary Amine (PSA) for each 1 mL aliquot. After the shaking step, the upper layer of the sample was transferred to a 5 mL centrifuge tube and acidified with 10 μ L formic acid. The solution was evaporated to dryness and dissolved with methane to 1 mL. Finally, the methane solution was analyzed by GC-MS/MS.

Instrumentation

The quantification analysis of both pesticides and their degradation products was performed using a gas chromatograph (Agilent 7890, UK) coupled with a tandem mass spectrometer. An autosampler (Shimadzu, Japan) was utilized to inject the sample solution. A silica capillary column coated with diphenyl-methyl polysiloxane was used as the stationary phase in GC. Perfluorotributylamine (PFTBA) was employed for the calibration of the MS spectrometer. The temperature program of GC was set in the following way: the initial temperature of 75°C, kept for 4 minutes;



increased up to 120°C with the time rate of 25°C min⁻¹; then, increased up to 300°C with the time rate of 50°C min⁻¹, and kept for 7 minutes. The inlet temperature, the flow gas, and the interface temperature were 250°C, 3 mL min⁻¹, and 280°C, respectively. The multi-reaction monitoring mode was applied for all of the compounds (diazinon, chlorpyrifos, and their oxon derivatives).

Validation Study

For the validation study, using the European Health and Consumer Guidelines, the Limit Of Quantification (LOQ), Limit Of Detection (LOD), linearity, recovery (%), and specificity of these compounds were evaluated. To determine the absolute recovery and Relative Standard Deviations (RSD), the spiked samples were prepared at three different levels (75, 100, and 125 µg kg⁻¹) and on three different days (Table1). The calibration curves of the peak areas

versus the concentrations of the compounds were constructed using eight concentration levels (5, 10, 25, 50, 75, 100, 125, and 200 µg kg⁻¹). The LOQs determined for this method were lower than those set by the EU and Iranian National Standards for pesticides (Table2).

All of the validation parameters (including recovery, repeatability, linearity, precision, and accuracy) met the acceptance criteria. According to the obtained values, this methodology is valid, selective, decisive, and potent for the evaluation of the metabolites and their parent pesticides in tomato samples.

Exposure Assessment and Risk Characterization

The estimated daily intake of a given pesticide is expressed as equation 1:

$$EDI = \frac{C_p \text{ (mg/kg)} \times F_c \text{ (kg/d)}}{BW} \quad (1)$$

Where, C_p is the Concentration of the

Table 1. The recoveries and RSDs of chlorpyrifos, diazinon, chlorpyrifos oxon, and diazoxon.

Insecticide	LOD (mg kg ⁻¹)	LOQ (mg kg ⁻¹)	Regression equation	R ²	MRL ^a (mg kg ⁻¹)	MRL ^b (mg kg ⁻¹)
Chlorpyrifos	0.027	0.083	y= 47.37x+758.56	0.996	0.1	0.1
Diazinon	0.003	0.01	y= 11.62x+70.74	0.993	0.01	0.05
Chlorpyrifos oxon	0.015	0.047	y= 31.16x+10.19	0.995	0.01	0.05
Diazoxon	0.012	0.039	y= 244.88x-615.31	0.993	0.01	0.05

^a EU standards, ^b Iranian national standards.

Table 2. LOD, LOQ and regression equation for target compounds.

Fortification (µg kg ⁻¹)	Mean final concentration	Mean recoveries	RSD
Chlorpyrifos	75	73.42	97.89
	100	103.54	103.54
	125	123.85	99.08
Diazinon	75	83.66	111.54
	100	107.96	107.96
	125	110.44	88.35
Chlorpyrifos oxon	75	101.06	75.80
	100	104.06	104.06
	125	95.64	119.56
Diazoxon	75	75.49	75.49
	100	100.27	100.27
	125	116.18	116.18

diazinon and chlorpyrifos in tomatoes, F_c is the Frequency of consumption, and BW is the Body Weight.

The residue levels of chlorpyrifos and diazinon at five days after pesticide application were considered as C_p for greenhouse, room, and refrigerator conditions, while, for cooking condition, the concentration of residual pesticides after two hours boiling were used in the equations. The body weights for the adults, adolescents, and children were set at 70.8, 43.2, and, 23.1 kg, respectively (Hlihor *et al.*, 2019). According to the survey of the National Nutrition and Food Technology Research Institute, the consumption rate was considered as $52 \text{ g person}^{-1} \text{ d}^{-1}$. The Hazard Quotient (HQ) was defined as the ratio of pesticide intake to ARfD or ADI using the following equations:

$$HQ_{\text{acute}} = EDI / \text{ARfD} \quad (2)$$

$$HQ_{\text{chronic}} = EDI / \text{ADI} \quad (3)$$

(acute reference dose) ARfD and acceptable daily intake (ADI) values were extracted from the EU pesticides database (Mojsak *et al.*, 2018).

Monte Carlo Simulation (MCS)

In the current research, the Monte Carlo simulation technique was utilized to evaluate the variability and uncertainty and to achieve more accurate results in the health risk assessment process. As an add-in program for Microsoft Excel, the Oracle Crystal Ball software (version 11.1.2.4) was used to predict the entire range of the probable results and to create graphical statistics for a specific situation. For this purpose, 1,000 iterations were used to solve equations 1-3 for different age groups.

RESULTS AND DISCUSSION

Concentration and Removal Rates of Diazinon, Chlorpyrifos, and Their Oxon Derivatives

In the greenhouse condition during 21 days, the rates of decline for diazinon and chlorpyrifos were obtained as 99.3 ± 3.2 and $95.5 \pm 4.1\%$, and their residue levels decreased from 1.9 to $0.01 \mu\text{g g}^{-1}$ and from 2.01 to $0.09 \mu\text{g g}^{-1}$, respectively. In the room temperature, 32.8 ± 0.8 and $27.2 \pm 2.5\%$ of diazinon and chlorpyrifos decreased, respectively, whereas in the refrigerator temperature, they decreased 23.1 ± 5.4 and $17.3 \pm 1.3\%$, respectively. The residue levels of chlorpyrifos and diazinon at the boiling temperature during two hours decreased from 2.7 to $1.05 \mu\text{g g}^{-1}$ and from 2.4 to $0.2 \mu\text{g g}^{-1}$, respectively.

According to the results, five days after pesticide application, the final concentrations of chlorpyrifos and diazinon in the greenhouse condition were much lower than those of room and refrigerator conditions. This may be due to the higher temperature, photolysis, and evaporation in the greenhouse conditions compared to the room and refrigerator conditions (Omirou *et al.*, 2009; Fenoll *et al.*, 2009).

In a study by Leili *et al.* (2016), the average reductions of ethion and imidacloprid residues after two days of storage at 4°C were obtained as 15.5 and 18.9% , respectively, while, in the greenhouse conditions, about 80% and 90% of their residues were removed. In another study by Pan *et al.* (2017) in the greenhouse conditions, five days after pesticide application, about 85% of pyrethrin residues were reduced from lettuce leaves. According to the findings by Fenoll *et al.* (2009), under cold storage conditions, no dissipation of pyriproxyfen and buprofezin were observed in peppers, and the removal rates of cyprodinil, fludioxonil and tebuconazole were negligible, while in the greenhouse condition, two weeks after application of the pesticides, the residues were considerably below the MRL. In another study by Aplada-Sarlis *et al.* (1999), there was a significant loss of teflubenzuron and triflumuron residues in pears under field condition within 2 days, while the



dissipation of the pesticide residues in cold-stored pears remained relatively stable for 6 weeks. Heshmati *et al.* (2020) stated that the dissipation rate of penconazole, hexaconazole, diazinon, ethion, and phosalone in grape under field (pre-harvest) condition was higher than its value at the post-harvest conditions (storage at 4 and 20°C).

During the cold storage and darkness, the processes of evaporation and photo degradation were negligible and, consequently, enzymatic degradation and dissipation of pesticides decreased (Marín *et al.*, 2003; Farha *et al.*, 2016).

In addition, as mentioned earlier, the removal rate of chlorpyrifos after 7 days storage at refrigerator was $17.3 \pm 1.3\%$, while at room, refrigerator and boiling temperatures this rate was obtained after 3 days, 1 day, and 45 minutes, respectively. In terms of diazinon, at refrigerator temperature, the reduction rate was $23.1 \pm 5.4\%$ after 7 days storage, whereas, to reach this removal rate at room, greenhouse, and boiling temperatures, 2 days, 1 day and 15 minutes were required, respectively. Therefore, it could be stated that with increasing temperature, the necessary time for dissipation of pesticides decreases.

It was observed that the removal rate of diazinon was more than those of chlorpyrifos residues in all conditions. This is possibly a result of the physical and chemical properties of diazinon such as its higher solubility, pressure volatility, and sensitivity to photodegradation, which leads to the more efficient removal of diazinon than chlorpyrifos residues. This is in agreement with the findings of Singh *et al.* (2017) who showed that the reduction values of diazinon and chlorpyrifos at 69°C were equal to 78.08 and 61%, respectively.

The oxon derivatives of organophosphorus pesticides can result in higher toxicity and risk to the environment and living organisms compared to their parent compounds (Kaur *et al.*, 2017).

In the current study, under laboratory and greenhouse conditions, chlorpyrifos oxon residue was detected in each sample after applying chlorpyrifos. However, diazoxon residue was below detection limit in the

entire samples analyzed. The residue levels of chlorpyrifos oxon fluctuated during field condition and its maximum value was equal to $488 \mu\text{g kg}^{-1}$ at 7 days following spraying. At boiling temperature, chlorpyrifos oxon varied from 224.8 to $170.5 \mu\text{g kg}^{-1}$, and at room and refrigerator temperatures ranged from 147.9 to $180.3 \mu\text{g kg}^{-1}$ and 53.07 to $202.6 \mu\text{g kg}^{-1}$, respectively (Figure 1).

It was also observed that the residue levels of both pesticides (chlorpyrifos and diazinon) and chlorpyrifos oxon in post-harvest processing (room, refrigerator, and boiling temperatures) were higher than the EU MRLs and the national standards established for tomato samples (Figure 2).

Exposure Assessment and Risk Characterization

According to the results of the Monte Carlo simulation, the acute HQ values of chlorpyrifos and diazinon in greenhouse condition ranged from 0.01-0.23 to 0.00-0.04 for adults, 0.02-0.35 to 0.01-0.06 for adolescents, and 0.04-0.76 to 0.01-0.15 for children, respectively. However, the chronic HQ values of chlorpyrifos and diazinon residues ranged from 0.24-0.85 to 0.06-1.09 for adults, 0.45-1.34 to 0.12-1.66 for adolescents, and 0.71-1.80 to 0.21-3.78 for children, respectively. Figure 3 shows the cumulative probability distribution diagrams of chronic and acute HQ for diazinon and chlorpyrifos residues in greenhouse condition and different age groups. The HQ values of both pesticides for adult and adolescent groups were lower than that of children. This is because the children (age group: 3 to 10 years) tend to eat more food commodities on a body weight basis; consequently, they are considered to be the most susceptible subpopulation (Mojsak *et al.*, 2018). Previous studies have reported similar results, associating the highest acute and chronic HQ values with the children age group (Asiri *et al.*, 2019; Mojsak *et al.*, 2018; Heshmati *et al.*, 2019). As illustrated in Figures 3 and 4, the

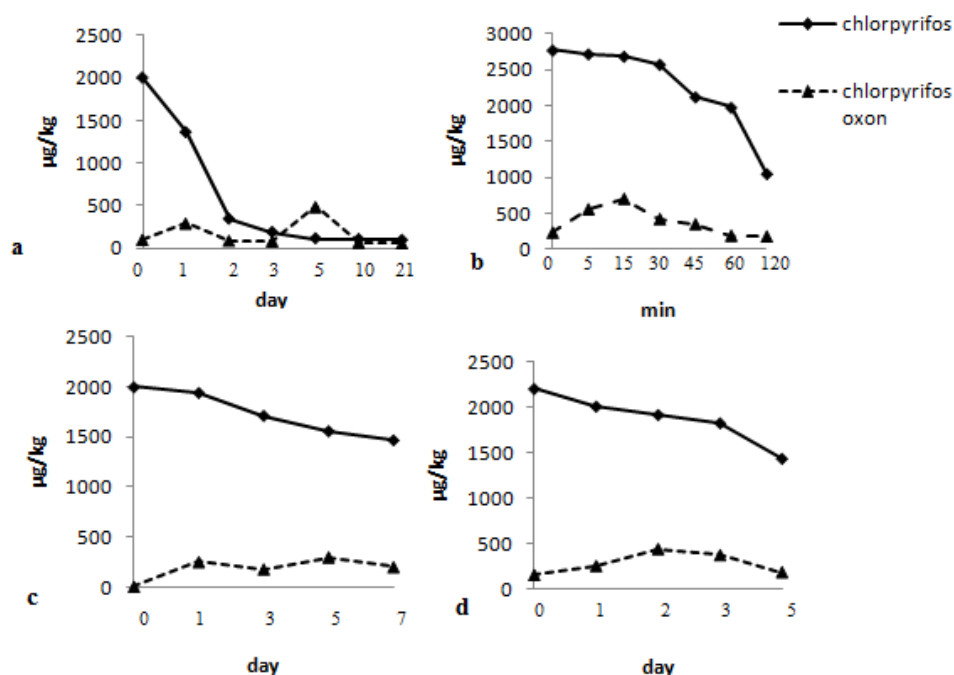
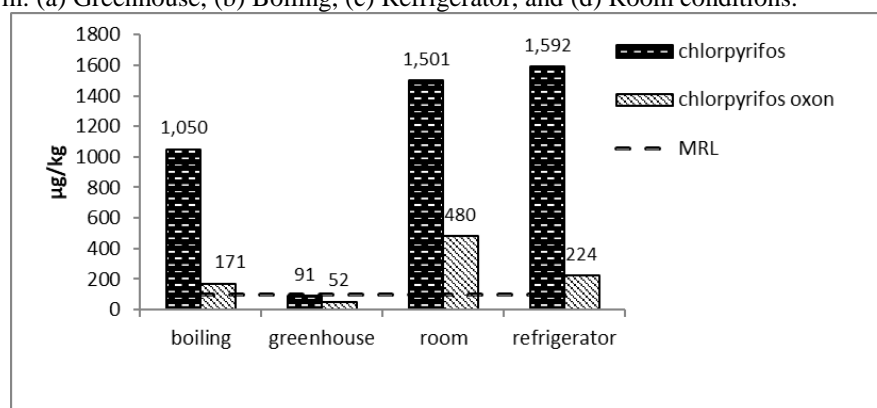
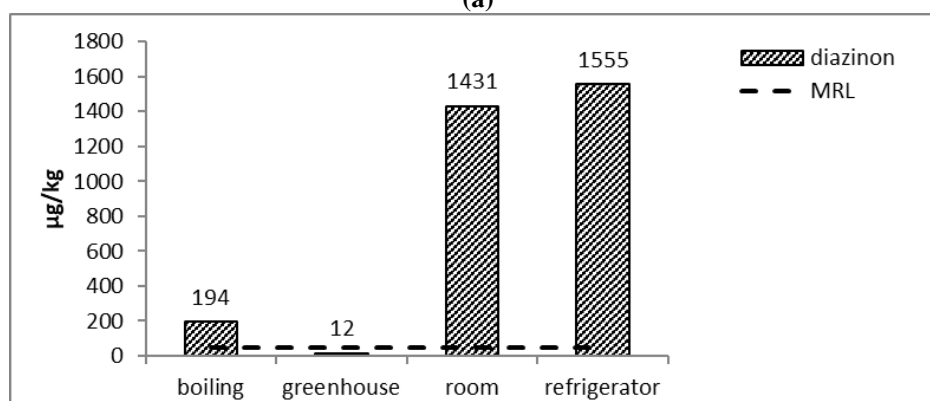


Figure 1. The dissipation of chlorpyrifos and its metabolite chlorpyrifos oxon in the tomato samples in: (a) Greenhouse, (b) Boiling, (c) Refrigerator, and (d) Room conditions.



(a)



(b)

Figure 2. The final concentration of (a) Chlorpyrifos and chlorpyrifos oxon, and (b) Diazinon.

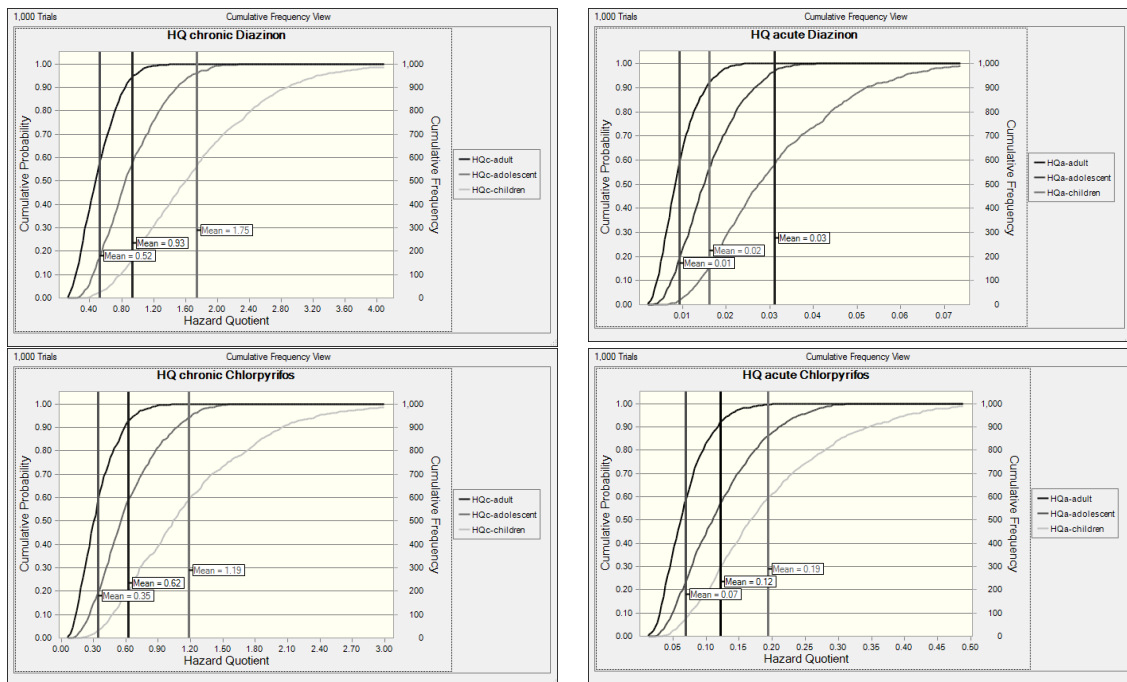


Figure 3. Cumulative probability distribution diagram of HQc and HQa in pre-harvest condition for diazinon and chlorpyrifos.

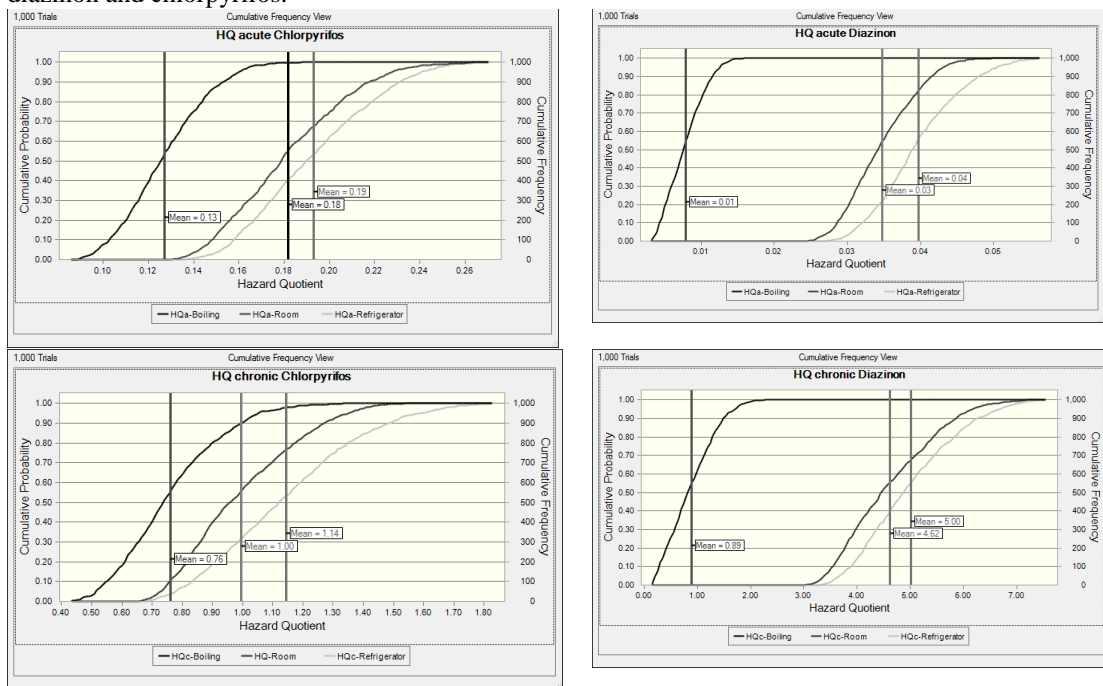


Figure 4. Cumulative probability distribution diagram of HQc and HQa in post-harvest conditions (including boiling, refrigerator, and room conditions) for diazinon and chlorpyrifos.

acute HQ values were below 1 in all conditions including pre- and post-harvest conditions, while the chronic HQ values were higher than the safe level in refrigerator condition for both pesticides, and in room temperature for diazinon. A consistent result was obtained by Silipunyo *et al.* (2017), who came to the conclusion that the short-term exposure to some organophosphates residues (such as diazinon and chlorpyrifos) through the consumption of fruits was not associated with health risk, whereas long-term risk assessment of these compounds, based on their relevant acute reference doses (ARfDs), was higher than 1 in certain groups of consumers. Data provided in a study by Liu *et al.* (2016) showed that short-term intake of organophosphates (acephate, dimethoate, chlorpyrifos and parathion-methyl) with the concentrations of 19.0 to 74.0 $\mu\text{g kg}^{-1}$ in nuts was below 1.2% of the ARfD.

Based on Figure 4, the tomato samples in boiling temperature (after two hours) were safer compared to the other post-harvest conditions. The results of dietary risk were consistent with those of previous studies showing that the potential health risk of pesticides was significantly reduced at higher temperatures (Zhao and Liu, 2020; Gong *et al.*, 2019). In one study by Alaboudi *et al.* (2019), the residue levels of hexachlorocyclohexane, aldrin, and malathion were quite stable during refrigeration storage, whereas heat treatment (boiling at 100°C) significantly reduced pesticides levels to values below MRL, and

the health risk indexes were greatly decreased. The sensitivity analysis was used to determine the influence rates of different parameters (including Cpest, Fc, and BW) on EDI, chronic HQ, and acute HQ. According to Figure 5, the HQ and EDI values were more affected by the consumption rate followed by pesticide concentration and body weight. Therefore, due to the high frequency of tomato consumption in the Iranian food basket, it is necessary to reduce pesticide concentrations in this product in order to reduce human health risk.

CONCLUSIONS

According to the current research, the removal rates of chlorpyrifos and diazinon were much higher in greenhouse and boiling conditions than those of room and refrigerator conditions. The data concerning the behavior of the mentioned pesticides during field condition demonstrates the importance of adopting appropriate harvesting protocols and following the pre-harvest intervals to ensure food safety for consumers. Among post-harvest processing, in refrigerator condition, the HQ values were significantly higher than those in other household processing; and the results highlighted a chronic risk for both pesticides in cold storage. The highest hazard quotient values were found in the children age group, and it could be stated that this age group is more sensitive to the

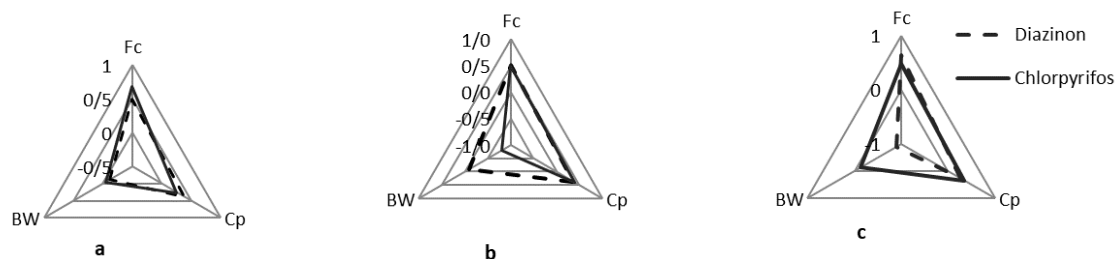


Figure 5. The rate of effect of three parameters (including Cp, Fc and BW) on EDI (a), HQa (b) and HQc (c) values.



risk of pesticides through fruit consumption than the other groups. Moreover, based on the findings of this study, chlorpyrifos oxon residue was found in the samples as intermediate product, and its concentration was higher than MRLs in all household processing; therefore, it is essential to pay special attention to the toxic metabolites by monitoring and evaluating their residues in agricultural products, designing and implementing training programs, and other legal interventions.

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ارزیابی ریسک مواجهه با باقیمانده سموم کلرپیریفوس و دیازینون در گوجه فرنگی های گلخانه ای در فاصله زمانی قبل از برداشت و فرآیندهای بعد از برداشت

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چکیده

هدف از این مطالعه تعیین میزان بقایای سموم دیازینون، کلرپیریفوس و متابولیت های فعال آن ها در گوجه-فرنگی گلخانه ای و برآورد شاخص های خطر حاد و مزمن در این محصولات می باشد. شناسایی و اندازه گیری غلظت سموم مورد مطالعه و متابولیت های آن ها به وسیله دستگاه کروماتوگرافی گازی مجهز به طیف سنج جرمی انجام شد. به منظور برآورد میزان عدم قطعیت در محاسبه داده ها و آنالیز دقیق یافته ها در ارزیابی ریسک، از شبیه سازی مونت کارلو استفاده گردید. دامنه مقادیر شاخص خطر مزمن برای کلرپیریفوس در گروه های سنی بزرگسالان، نوجوانان و کودکان به ترتیب ۰/۸۵-۰/۲۴، ۰/۳۴-۰/۴۵ و ۰/۸۰-۰/۷۱ و برای دیازینون به ترتیب ۰/۰۹-۰/۰۶، ۰/۶۶-۰/۱۲ و ۰/۷۸-۰/۲۱ به دست آمد. بعد از ۵ روز نگهداری نمونه ها در دماهای اتاق و یخچال مقادیر شاخص های خطر برای سموم دیازینون و کلرپیریفوس، بیش از حدود قابل قبول گزارش شد. در شبیه سازی مونت کارلو در بین پارامترهای مورد ارزیابی به ترتیب میزان اثر، پارامترهای میزان مصرف، غلظت باقی مانده سموم و وزن بدن در اندازه گیری مقادیر EDI و HQ نقش داشتند. بنابراین با توجه به بالا بودن میزان مصرف بالای گوجه فرنگی در سبد غذایی مردم، جهت کاهش ریسک سموم در مواد غذایی نیاز است که غلظت بقایای سموم آفت کش در محصولات کشاورزی هر چه بیشتر کاهش یابد.