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Estimation of human health risk associated with the consumption of pesticide-contaminated vegetables from Kumasi, Ghana

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Abstract Analysis of pesticides consisting of 12 organophosphates (OPs), 10 organochlorines (OCs), and 6 pyrethroids in vegetables from Kumasi was conducted. Vegetable samples comprising 20 each of eggplants, okra, and tomatoes were analyzed. The method involves solvent extraction of pesticide residues followed by cleanup using silica gel. Residue analysis was carried out using a GC equipped with pulsed flame photometric detector for OP residues and electron capture detector for OC and pyrethroid residues. The results revealed that methamidophos exceeded the maximum residue limits (MRLs) in all vegetable commodities. Levels of malathion and dimethoate also exceeded the MRLs in eggplant and tomato samples. Endrin, α-endosulfan, γ-hexachlorocyclohexane (HCH), γ-chlordane, and heptachlor exceeded their MRLs in okra samples whereas methoxychlor, allethrin, and deltamethrin exceeded in eggplant samples. Health risk estimation revealed that dimethoate in tomato and endrin, heptachlor, γ-HCH, and γ-chlordane in okra could not pose potential toxicity to the consumer. The combined risk index showed no health risk to consumers due to intake of pyrethroid OC and OP residue on these vegetables. The overall risk index for combined pesticides due to consumption of all the vegetables was higher than 1, which signifies potential health risk to consumers. OPs were the major risk contributor for both eggplant and tomatoes which accounted for 87.78 and 95.84 %, respectively, of the combined risk of pesticides in the vegetables. However, OC with 97.94 % of the combined risk index was the major risk contributor for the okra. The carcinogenic risk of the OCs in okra was of no concern since their carcinogenic rates were below the acceptable risk level.

Keywords Contamination · Consumption · Health risk · Kumasi · Pesticide residue · Vegetables

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Introduction

Worldwide demand for food is growing mainly due to increasing population. One side effect of improving food production is increased use of pesticides to protect crops from damage infested by insects and fungi and reduce completion from weeds (Paker 2013; Iya and Kwaghe 2007; Al-Eed et al. 2006). All developing countries with growing population therefore require pesticides to boost food production (Amoah et al. 2006). Vegetables are important ingredients of human diet and have high nutritional value by providing vitamins and minerals (Dixon 1985). Vegetables such as *Abelmoschus esculentus* (okra), *Solanum melongena* (eggplant), and *Solanum lycopersium* (tomatoes) are widely cultivated in Ghana for local consumption and exports (Gyau and Spiller 2007; Lamptey et al. 2004). Vegetable production is therefore a key component of Ghana's food security strategy (Parker et al. 2010). Unfortunately, vegetable cultivation is affected by pests, which demands the use of pesticides to control them.

About 87 % of the farmers who grow vegetables in Ghana use pesticides (Akoto et al. 2013; Dinham 2003). It has been reported that most of these vegetable farmers apply a wide range of different pesticides during the entire period of growth, where no pre-harvest time frame after application is maintained because of the high demand for these vegetables (Ntow et al. 2006; Darko and Akoto 2008). Again, studies conducted by Horna et al. (2008) indicated that these vegetable growers with low perception of the toxic effect of pesticides use higher than recommended doses of pesticides on crops. These and other indiscreet practice related to pesticide usage had resulted in the occurrence of high pesticide residue on vegetables. The presence of these pesticide residues in vegetables has always been a matter of serious concern and can lead to serious chronic health hazards especially when these vegetables are consumed fresh (Baig et al. 2009).

Epidemiological and other laboratory studies in animals have shown that exposure to different classes of pesticides such as organochlorine (OC), organophosphate (OP), carbamate, and pyrethroids has adverse health effects including cancer, birth defects, reproductive defect, neurological and developmental impairment, immunotoxicity, and disruption of the endocrine system (Bassil et al. 2007; Longnecker et al. 1997).

The use of pesticides in Ghana is assuming alarming proportions and calls for thorough studies into it (Akoto et al. 2013; Darko and Acquah 2008). Unfortunately, recent data on the extent of pesticide contamination of vegetables sold on the Ghanaian market is lacking. The objectives of this study were to evaluate the residual concentrations of the pesticides in some vegetables commonly grown in Ghana and assess the health risk implications associated with the consumptions of these vegetables.

Materials and methods

Sample collection

Vegetable samples were collected from different sellers at the Kumasi Central market in March 2013 and kept in polypropylene sealable sampling bags. Sample bags were labeled and transported to the laboratory where they were kept refrigerated until further analysis. A total of 60 fresh vegetable samples comprising 20 samples of okra, 20 samples of eggplant, and 20 samples of tomato were used. These vegetables were selected for this study due to their commercial importance and high consumption. According to a market survey conducted in three markets (Accra, Kumasi, and Koforidua) by Agri-Impact Consult, tomatoes, onions, cabbages, eggplant, and okra are the top most favorite vegetables in the metropolitan areas (Agri-Impact Consult 2014).

Reagents and glassware

All glassware used for extraction and cleaning was rigorously washed with tap water and detergent and rinsed twice with distilled water. They were again rinsed with acetone and finally dried in an oven. All solvents and reagents used were of the analytical grade supplied by BDH Chemical Ltd., UK. Individual pesticide standards were available at the Ghana Standards Authority (GSA) laboratories in Accra.

Extraction and cleanup of pesticide residues

The vegetable samples (okra, eggplants, and tomatoes) were homogenized, and approximately 15.0 of the homogenized samples were macerated with 20 mL of acetone in a 100-mL volumetric flask. The samples were placed in a mechanical shaker at a speed of 1400 rpm and shaken for 4 h. The contents were allowed to settle, and the organic phase was decanted and filtered into a conical flask. The extracts were transferred into a separatory funnel packed with 20 g of sodium sulfate activated at 160 °C. This was performed to remove traces of moisture from the extract. The EPA method 3630C was employed for cleanup with slight modification. The column for cleanup was pre-eluted with 5 mL of hexane. Two grams of silica gel and 1 g of sodium sulfate were transferred into the column, respectively. About 5 mL of hexane was then added to wet and rinse the sodium sulfate and silica gel in the column. The sample extract was dissolved in 2 mL hexane and transferred onto the column. The extract was rinsed twice with hexane and each rinse added to the column. The column was eluted with 10 mL of hexane and finally washed with 5 mL of acetone. Cleanup was carried out to remove compounds of different polarity that can interfere with the analysis. The eluate was concentrated to approximately 2 mL on a rotary evaporator at 37 °C. The final extracts were kept in suitable vials and refrigerated until GC analysis.

GC analysis

Before analysis, recovery experiments were carried out on samples fortified at 0.5 mg/kg by adding standard pesticide solutions. The samples were allowed to equilibrate for 30 min prior to extraction. The spiked samples were extracted and analyzed under the same conditions as the samples. After extraction and solvent evaporation, the samples were analyzed according to the proposed method. The recovery values were calculated from calibration curves constructed from the concentration and peak area of the chromatograms obtained with the pesticide standards. GC equipped with electron capture detector (ECD) and pulsed flame photometric detector (PFPD) was checked for limit of detection. Instrumental limit of detection for OCs was 0.005 mg/kg, for pyrethroid pesticides was 0.001 mg/kg, and for OPs was 0.001 mg/kg. Blank analyses were also performed in order to check interference from the sample. All analyses were carried out in triplicates, and the mean concentrations were calculated. Separation and quantification of OP pesticide residues were carried out using Varian CP-3800 gas chromatograph with a CombiPAL autosampler equipped with PFPD on 30-mm by 0.25-mm internal diameter fused silica capillary column coated with VF-1701 ms (0.25-μm film). The column oven temperature was performed as follows: initial temperature 70 °C, then increased to 200 °C at a rate of 25 °C/min, and then ramped to 250 °C at a rate of 20 °C/min, keeping the final temperature for 2 min. The carrier gas was nitrogen gas at the flow rate of 2 mL/min. The injector and detector temperatures were maintained at 250 and 280 °C, respectively. The injector volume of the GC was 2.0 μL.

Separation and quantification of OC and synthetic pyrethroid pesticides were carried out using Varian CP-3800 gas chromatograph with a CombiPAL autosampler equipped with an electron capture detector (ECD, 63Ni), on 30 mm+10 EZ Guard×0.25-mm internal diameter fused silica capillary column coated with VF-1701 ms (0.25-μm film). The column oven temperature was programmed from 70 °C, held for 2 min, and increased to 180 °C at a rate of 25 °C/min, then from 180 °C to ECD temperature set at 300 °C at a rate of 5 °C/min. The carrier gas was purified nitrogen gas at the flow rate of 1 mL/min and make up gas of 29 mL/min. The injector and detector temperatures were maintained at 300 °C. The injector volume of the GC was 1.0 μL.

The data obtained in this study were recorded in Microsoft Excel (Spreadsheet Version 12) spreadsheets and subjected to statistical analyses. Lack of significant variations for pesticide residues within specific samples ($P>0.05$) resulted in using the mean values for further assessment such as risk and estimation of daily intake. The mean residue levels were obtained for comparison to European Union (EU)-recommended guidelines.

Estimation of daily intakes

The estimated daily intake (EDI) based on the average body weight of a Ghanaian was obtained by multiplying the mean residual concentration (mg/kg) of each pesticide residue in the vegetable by the FAO per capita food consumption rates of the respective vegetable and dividing the product by a standard body weight (kg) (Wang et al. 2011; Akoto et al. 2013). The per capita food consumption rate of tomato is 0.037 kg/day, of eggplant is 0.047 kg/day, and of okra is 0.041 kg/day (FAO 2013). Average adult body weight of a Ghanaian was considered to be 60 kg.

Thus,

$$\mathrm{EDI} = \frac{C_\mathrm{p} \times \mathrm{FCR}}{\mathrm{BW}}$$

where EDI is the estimated daily intake, C_p is the concentration of the pesticide, FCR is the food consumption rate, and BW is the average body weight of a Ghanaian.

Risk assessment

Potential health risk index (HRI) for noncarcinogenic effect for the individual pesticide residue in the vegetables was estimated by dividing the EDI by their corresponding acceptable daily intake (ADI) values as presented in the equation below. When HRI is greater than 1, it indicates that lifetime consumption of vegetable containing the measured level of pesticide residues could pose health risks (FAO 2013; Wang et al. 2011; Darko and Akoto 2008). The HRI was calculated by using the equation below:

$$\mathrm{HRI} = \frac{\mathrm{EDI}}{\mathrm{ADI}}$$

Combined risk of multiple pollutants

It has been reported that exposure to two or more pollutants may result in additive and/or interactive effects

Table 1 Concentration, EDI, and health risk estimation for OP residues measured in eggplant samples (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
Methamidophos	0.014±0.001	0.010	0.004	1.1×10^{-3}	2.7×10^{-3}	No
Dimethoate	0.002±0.001	0.020	0.002	1.6×10^{-3}	7.8×10^{-1}	No
Chlorpyrifos	0.098±0.094	0.500	0.01	7.7×10^{-5}	7.7×10^{-3}	No
Parathion-et	0.005±0.006	0.050	0.004	3.9×10^{-6}	9.8×10^{-4}	No
Chlorfenvinphos	0.009±0.002	0.020	0.0005	7.1×10^{-6}	4.1×10^{-2}	No
Malathion	0.117±0.001	0.020	0.300	9.2×10^{-5}	3.1×10^{-5}	No

(Saha and Zaman 2012; Reffstrup et al. 2010). The hazard index method proposed by the US EPA has been used to assess risk posed by a group of pesticides that act by a common mechanism or that are toxicologically similar (US EPA 2000; Reffstrup et al. 2010). The combined hazard index (HI) was estimated using the equation below (Reffstrup et al. 2010).

$$\mathrm{HI} = \frac{E_1}{A_1} + \frac{E_2}{E_2} + \ldots + \frac{E_n}{A_n} = \sum_{i=1}^{n} \frac{E_i}{A_i}$$

where E_1, E_2, E_n, and E_i are the levels of exposure of each individual pesticide (i) in a mixture of n pesticides. A_1, A_2, A_n, and A_i are the maximum acceptable levels (ADIs) for each pesticide (US EPA 2000). If the hazard index exceeds 1, the mixture has exceeded the maximum acceptable level and there might be a risk to consumers.

Overall risk effect of pesticide residue in vegetables

The approach developed by US EPA (1986) was used to assess the overall potential risk for noncarcinogenic effects posed by a specific receptor/pathway combination (e.g., diet). This was calculated as the sum of all the combined risk effects of all the pesticide groups present in the vegetables which are used to prepare the diet.

Carcinogenic risk

The lifetime carcinogenic risk of OC pesticides was estimated by the equation below (Wang et al. 2011; Dougherty et al. 2000).

$$\mathrm{HR} = \frac{\mathrm{EDI}}{\mathrm{CBC}}$$

where HR is the hazard ratio, EDI is the estimated daily intake, and CBC is the cancer benchmark concentration calculated using the formula below (Wang et al. 2011). HR exceeding 1 indicates that there is potential risk to human health.

$$\mathrm{CBC} = \frac{\left(\frac{\mathrm{RL}}{\mathrm{OSF}} \times \mathrm{BW}\right)}{\mathrm{CR}}$$

where RL is the maximum acceptable risk level for cancer benchmark (1×10^{-6}) (Han et al. 1998), OSF is the oral slope factor, BW is the body weight (kg), and CR is the consumption rate.

Results and discussion

A total of 60 vegetable samples (eggplants, okra, and tomato) were analyzed for the presence of 10 OC, 12 OPs, and 6 pyrethroid pesticide residues. The results of the analysis are presented in the tables below.

Concentrations of six of the OP pesticide residues in the investigated eggplant samples (diazinon, profenos, ethoprophos, phorate, fenitrothion, and pirimiphos-methyl) were below the detection limit (0.001 mg/kg) of the instrument. The remaining six comprising methamidophos, dimethoate, chlorpyrifos, parathion-et, chlorfenvinphos, and malathion, however, were detected at varying concentrations in the eggplant samples.

Table 2 Concentration, EDI, and health risk estimation for OC residues measured in eggplant samples (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
Methoxychlor	0.062±0.001	0.010	0.1	4.9×10^{-5}	4.9×10^{-4}	No

Table 3 Concentration, EDI, and health risk estimation for pyrethroid residues measured in egg plant samples (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
Allethrin	0.126±0.018	0.010	NA	7.5×10^{-5}	–	–
Deltamethrin	0.039±0.003	0.050	0.01	3.1×10^{-5}	3.1×10^{-3}	No
Permethrin	0.003±0.010	0.300	0.05	2.4×10^{-6}	4.7×10^{-5}	No

The highest mean concentration of 0.1 17±0.001 mg/kg was recorded for malathion, and the lowest of 0.002± 0.001 mg/kg was recorded for dimethoate in 35 % of the samples. Methamidophos was detected in all the samples at a mean concentration of 0.0144±0.001 mg/kg. The mean concentrations of malathion which was detected in 70 % of the samples and those of methamidophos were higher than their corresponding maximum residue limit (MRL) values (EU 2013) (Table 1).

Chlorpyrifos was detected in 65 % of the samples at a mean concentration of 0.098±0.094 mg/kg. Mean concentrations of chlorpyrifos, chlorfenvinphos, and parathion-et were below their MRL values set by the EU. Hazard indices for all detected OPs were below one (<1) (Table 1) and therefore presented no health risk to consumers. Of all the hazard indices obtained, dimethoate was recorded as the highest and the lowest was recorded for malathion. Methoxychlor was the only OC pesticide that was detected in 55 % the eggplant samples. Mean methoxychlor residue concentration (0.062 ±0.001 mg/kg) in the samples was higher than its MRL of 0.010 mg/kg (EU 2013) (Table 2). The health HI calculated for methoxychlor was 4.9×10^{-4} and therefore presented no health risk to consumers. All the other OCs comprising δ-hexachlorocyclohexane (HCH), heptachlor, aldrin, -chlordane, p,p[1]-dichlorodiphenyltrichloroethane (DDT), -HCH, β-endosulfan, p,p-dichlorodiphenyldichloroethane (DDD), endosulfan, and endrin were below the detection limit of 0.005 mg/kg. Among all the pyrethroid pesticides considered in the eggplant examples, only permethrin, allethrin, and deltamethrin were detected in the samples. The highest mean concentration of the pyrethroid pesticides was 0.126±0.018 mg/kg recorded as allethrin residue, and lowest of 0.003±0.000 mg/kg was recorded as permethrin residue. Allethrin was detected in all the eggplant samples. Permethrin and deltamethrin were detected in 35 and 55 %, respectively, in the eggplant samples. Levels of permethrin and deltamethrin residues in the samples were below the EU MRL values of 0.050 and 0.300 mg/kg, respectively, while allethrin exceeded its MRL value of 0.010 mg/kg (EU 2013) (Table 3). The hazard indices of both permethrin and deltamethrin were below 1 and therefore posed no health risk though deltamethrin had a higher HI than permethrin. However, the ADI of allethrin was not available, and therefore, its hazard or health index could not be determined. The other pyrethroid pesticides that were considered in this work were cypermethrin, fenvalerate, and cyfluthrin, but their residues were below the detection limit. It is clear that the individual pesticide residue detected in the eggplant does not pose any possible health hazard to consumers.

Results of OP residues that were investigated in the tomato samples are presented in Table 4. The mean residual concentrations of OP pesticide residues in tomato samples were in the range 0.003±0.002 to 0.155± 0.111 mg/kg. The highest mean concentration was recorded for dimethoate, and the lowest was recorded for

Table 4 Concentration, EDI, and health risk estimation for OP residues detected in tomato samples (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
Methamidophos	0.013±0.002	0.010	0.0040	8.1×10^{-6}	2.1×10^{-3}	No
Malathion	0.027±0.021	0.020	0.3000	1.7×10^{-5}	5.6×10^{-5}	No
Dimethoate	0.155±0.113	0.020	0.0020	9.6×10^{-5}	4.8×10^{-2}	No
Chlorpyrifos	0.065±0.002	0.500	0.0100	4.0×10^{-5}	4.1×10^{-3}	No
Chlorfenvinphos	0.006±0.001	0.020	0.0005	3.7×10^{-6}	7.4×10^{-3}	No
Phorate	0.010±0.020	0.050	0.0007	6.2×10^{-6}	8.8×10^{-3}	No

Table 5 Concentration, EDI, and health risk estimation for pyrethroid residues detected in tomato samples (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
Deltamethrin	0.045±0.037	0.300	0.0100	2.8×10^{-5}	2.8×10^{-3}	No
Permethrin	0.016±0.001	0.050	0.0500	9.1×10^{-6}	2.0×10^{-4}	No

profenofos. Levels of ethoprophos and pirimiphos-methyl in the tomato samples were below the instrument's detection limit. But, the levels of methamidophos, dimethoate, profenofos, chlorpyrifos, malathion, chorate, and chlorfenvinphos were above the detection limit of the instrument. Comparing the mean concentrations to the EU MRL, it was observed that methamidophos, the most frequently detected OP residue in the tomato samples, occurred at a mean concentration of 0.013±0.002 mg/kg in 85 % of the samples which was higher than the MRL value (EU 2013) (Table 4). Malathion was detected in 50 % of the samples at a mean concentration of 0.027±0.021 mg/kg while dimethoate occurred in 15 samples at a mean concentration of 0.155±0.113 mg/kg. Levels of malathion and dimethoate in the tomato samples were higher than their MRL values (Table 4). Chlorpyrifos was observed in 75 % of the samples at a mean concentration of 0.098±0.094 mg/kg while chlorfenvinphos also recorded a mean concentration of 0.009±0.002 mg/kg in 25 % of the samples. Health hazard indices of the OP residue detected in the tomato sample could not pose any health risk to consumers since their hazard indices were below 1, though some had their residues levels above the MRL values. All the OC pesticide residues measured in the tomato samples were below the instrumental detection limit. The pesticides were -chlordane, p,p[1]-DDT, methoxychlor, endrin, δ-HCH, -HCH, heptachlor, endosulfan, p,p-DDD, α-endosulfan, and β-endosulfan.

Only two of the pyrethroid pesticide residues (deltamethrin and permethrin) were detected in the tomato samples. Deltamethrin was detected in 50 % of the samples with a mean concentration of 0.045±0.037 mg/kg, and permethrin with a mean concentration of 0.016±0.001 mg/kg was detected in 25 % of the samples. The concentrations of deltamethrin and permethrin in the tomatoes were below their respective EU MRL values of 0.300 and 0.050 mg/kg. The hazard indices determined for deltamethrin and permethrin (Table 5) were all less than 1 and therefore presented no health risk to the consumer.

Table 6 presented the results of OP pesticide residues that were detected in the okra samples. Chlorpyrifos which occurred in 75 % of the samples recorded the highest mean concentration of 0.017±0.026 mg/kg. Phorate had the lowest mean concentration of 0.001±0.001 mg/kg which occurred in 25 % of the samples. Methamidophos which occurred in all the samples at a mean concentration of 0.013±0.003 mg/kg was found to be above its MRL value of 0.010 mg/kg. Profenofos was present in only 20 % of the samples at a mean concentration of 0.005±0.001. The hazard indices of these pesticides were all below 1 (Table 6) and therefore presented no health risks to the consumer. Five of the OC pesticide residues (methoxychlor, p,p′-DDT, β-endosulfan, p,p[1]-DDD, and endosulfan) that were measured in the okra samples had their concentrations below the detection limit of 0.005 mg/kg. The other five, -HCH, heptachlor, α-endosulfan, -chlordane, and endrin, had their residues detected at different concentrations in the samples (Table 7). -HCH which recorded the highest mean concentration of 0.605±0.124 mg/kg occurred in all the samples while heptachlor recorded the lowest mean concentration of 0.03±0.001 mg/kg in 60 % of the samples.

Table 6 Concentration, EDI, and health risk estimation for OP residues detected in okra samples (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
Methamidophos	0.013±0.003	0.010	0.0040	8.9×10^{-6}	2.2×10^{-3}	No
Phorate	0.001±0.001	0.050	0.0007	6.8×10^{-7}	9.7×10^{-4}	No
Chlorpyrifos	0.017±0.026	0.500	0.0100	1.2×10^{-5}	1.2×10^{-3}	No
Profenofos	0.005±0.013	0.050	0.0300	2.7×10^{-6}	6.8×10^{-5}	No

Table 7 Concentration, EDI, and health risk estimation for OC residues detected in okra samples (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
-HCH	0.605±0.124	0.010	0.008	4.1×10^{-4}	5.2×10^{-2}	No
Heptachlor	0.030±0.001	0.010	0.0001	2.1×10^{-5}	2.1×10^{-1}	No
α-Endosulfan	0.089±0.011	0.050	0.006	6.1×10^{-4}	1.0×10^{-1}	No
-Chlordane	0.047±0.001	0.010	0.0005	3.2×10^{-5}	6.4×10^{-2}	No
Endrin	0.043±0.001	0.010	0.0002	2.9×10^{-5}	1.5×10^{-1}	No

Ɣ-Chlordane and endrin recorded mean residue levels 0.045±0.001 and 0.041±0.001 mg/kg in 55 and 80 % of samples, respectively. All the OC pesticide residues detected had their mean concentrations above their corresponding MRL values (Table 7). The high residue of some OCs in the okra samples is an indication of recent use on okra farms, though OCs have banned for agricultural purposes in Ghana. Based on the average body weight of Ghanaians, the EDI of the OCs in the okra samples ranged from 3.2×10^{-5} to 4.1×10^{-4} mg/kg/day for endrin and Ɣ-HCH, respectively. The EDIs of the individual OCs were below the ADI for noncarcinogenic effects (Table 7). This, however, does not necessarily suggest that there is no potential health risk associated with okra consumed in Kumasi. The results of this study indicated that the mean concentrations of all the OC pesticides presented in the okra samples were higher than the maximum acceptable limits suggested by EU. Although the hazard indices of all the OCs in the okra were less than 1 and therefore indicate no health risk;, these OC pesticides could accumulate in fatty tissues of consumers and exert chronic health effect. Heptachlor had the highest hazard index whereas α-endosulfan recorded the lowest hazard index as presented in Table 7. The probabilities of lifetime cancer hazard risks posed by γ-chlordane, heptachlor, and Ɣ-chlordane through the consumption of okra from the study area were 6.3×10^{-2}, 3.2×10^{-1}, and 2.3×10^{-1}, respectively. These values are less than 1 (Table 10) and therefore raise no concern for carcinogenic risk of γ-chlordane, heptachlor, and Ɣ-chlordane in the vegetable.

Concentrations of pyrethroid pesticide residues determined in okra samples, their MRLs, and their hazard indices are presented in Table 8. Among all the pyrethroid pesticide residues measured in the okra samples, only deltamethrin and cypermethrin were present at detectable levels. Cypermethrin detected in 12 samples recorded mean concentration of 0.133±0.001 mg/kg, and deltamethrin had mean concentration of 0.016± 0.011 mg/kg in 50 % of the samples. Cypermethrin and deltamethrin had their mean concentrations below their respective MRL values of 0.500 mg/kg and 0.300 mg/kg (EU 2013). The hazard indices for cypermethrin (0.27) and deltamethrin (0.06) were below one (<1) and therefore presented no health risks to the consumer.

The combined health risk estimated by the individual groups of pesticides detected in the vegetable samples is represented in Table 9.

The combined health risks due to OPs in eggplant and tomatoes and okra were 0.806, 0.069, and 0.005, respectively, suggesting that people in Kumasi have no significant health risk through the consumption of these vegetables since all the calculated values were less than 1. The OCs recorded a combined health risk effect of 0.486 in the okra, indicating that consumers in Kumasi may not experience serious lifetime adverse health effects; again, the combined risk of OC in eggplant was less than 1. The combined risk due to pyrethroid residues in all the vegetables was less than 1. OPs were the major risk contributor for both eggplant and tomatoes which accounted for 94.20 and 94.74 %, respectively, of the combined risk of pesticides in the vegetables.

Table 8 Concentration, EDI, and health risk estimation for pyrethroid residues detected in okra (n=20)

Pesticide	Mean±SD (mg/kg)	EU MRL (mg/kg)	ADI (mg/kg/day)	EDI (mg/kg/day)	HI	HR
Cypermethrin	0.133±0.001	0.500	0.0200	9.1×10^{-5}	4.5×10^{-3}	No
Deltamethrin	0.016±0.011	0.300	0.0100	1.1×10^{-5}	1.1×10^{-3}	No

Table 9 Combined risk of multiple pesticides in the vegetables

Pesticides	Eggplant	Tomatoes	Okra
OPs	0.806	0.069	0.005
OCs	0.001	–	0.486
Pyrethroids	0.003	0.003	0.006
Total	0.810	0.072	0.497

However, OCs with 94.91 % of the combined risk index were the major risk contributor for the okra.

The overall potential risk for noncarcinogenic effects through consumption of a diet prepared from these selected vegetables is 1.38, indicating that consumers of Kumasi and its surrounding towns may experience adverse health effects for consuming diets prepared from these vegetables. This value was arrived at by adding all the combined health risks for the individual pesticides in the vegetables as described by Saha and Zaman (2012). The relative contributions of eggplant, tomatoes, and okra to the overall health risk were 5.52, 4.32, and 89.60 % respectively. The OPs contributed about 65.60 %; hence, it was the main component contributing to the potential health risk, with OCs being secondary and pyrethroids being the least important.

Conclusion

This study has shown that there were some degrees of pesticide contaminations in vegetables consumed in Kumasi. Comparing residual concentration of various pesticides in the vegetable samples with the EU MRLs, the residual levels of methamidophos were found to be exceeding the MRLs in all three vegetable samples. Malathion and dimethoate were also found to be exceeding the MRLs in both eggplant and tomato samples. Endrin, α-endosulfan, γ-HCH, γ-chlordane, and heptachlor exceeded their MRLs in okra samples whereas methoxychlor, allethrin, and deltamethrin exceeded in eggplant samples. The findings also show that OC pesticides are used mainly in okra farms within the study area.

Health risk estimation revealed that dimethoate and malathion, though exceeded their MRLs in tomato and egg plant, could not pose potential toxicity to the consumer. The combined risk index values showed that there was no health risk for consumers due to intake of OP, OC, and pyrethroid pesticide residues on these vegetables. The overall risk index for combined pesticides due to consumption of all the vegetables was higher than 1, which signifies potential health risk to consumers. The carcinogenic risk of the OCs in okra was also of less concern since their carcinogenic rates in individual vegetables were below the acceptable risk level (Table 10). It is suggested that constant monitoring of OP and OC pesticide residues is needed on all food commodities in order to evaluate if any potential health risks from pesticides exposure do exist, to assure food safety.

Table 10 Carcinogenic risk estimation for the OP residue detected in the okra

Pesticide	OSF	EDI	CBC	HR
Heptachlor	4.50	2.1×10^{-5}	6.6×10^{-3}	3.3×10^{-1}
-Chlordane	0.35	3.2×10^{-5}	5.1×10^{-4}	6.3×10^{-1}
-HCH	1.30	4.1×10^{-4}	1.90×10^{-3}	2.3×10^{-1}

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