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# Pesticides residues in leafy green vegetables and irrigation waters in Accra, Ghana

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**ABSTRACT**

Pesticides are used in vegetable farming to control pests and diseases, reduce crop losses and improve yield. The study examined pesticide residues in irrigation waters and leafy green vegetables grown in some farming areas in Accra, Ghana. Three types of irrigation water sources ($n = 23$) and two exotic and four indigenous Ghanaian leafy vegetables ($n = 34$) from 10 farming areas in Accra, Ghana were collected and examined for 15 organochlorines, 13 organophosphorus and 9 synthetic pyrethroids pesticide residues using the modified QuEChERS procedure. Pesticide residues were detected on 50% (17/34) of the leafy vegetable and 52% (12/23) of the irrigation water samples analysed. Chlorpyrifos and deltamethrin were the most detected pesticide residues in the vegetables and irrigation water. About 26.5% of the vegetables contained pesticide residues exceeding the EU maximum residue limits, so vegetable farmers should be encouraged to comply with appropriate measures on pesticide use to enhance food safety.

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Leafy green vegetables; irrigation water; pesticide residues; organophosphorus; synthetic pyrethroids; food safety

## Introduction

Vegetable farming is practiced in major cities in Ghana and they are a significant source of income, as well as fresh produce for the table. Various types of exotic (lettuce, cabbage, cauliflower, spinach, broccoli, Chinese cabbage) and indigenous (cocoyam leaves, *Amaranthus* sp, *Solanum macrocarpon*, *Hibiscus sabdariffa*, *Corchorus olitorius*, cowpea leaves) Ghanaian vegetables are cultivated (Danso et al. 2014; Quansah et al. 2020). According to Dinham (2003), vegetables attract a wide range of pests and diseases during cultivation, thus, intensive pest management is necessary in vegetable farming.

Pesticides are chemicals designed to kill or control insects, weeds, fungi, rodents and microbes. The major groups of pesticides based on target pest organisms include herbicides, insecticides, fungicides, nematicides and rodenticides (Fernandez-Cornejo et al. 2014; Yadav and Devi 2017). Pesticides consist of active ingredients that are used to control pests and inert ingredients that improve the safety, handling, application and storage of pesticides (Fernandez-Cornejo et al. 2014). Pesticides can be categorised based on the chemical composition of active ingredients such as organochlorines, organophosphates, pyrethroid, neonicotinoids and carbamates (Yadav and Devi 2017; US Environmental Protection Agency 2022).

Pesticides with different active ingredients are used in vegetable farming to control pests and diseases, reduce crop losses and improve yield. Some pesticides used in vegetable farming in Ghana include Akape (Imidacloprid), Attack (Emamectin benzoate), Bypel 1 (PrGv.Bt), Golan (Acetamiprid), Mectin (Abamectin), Sunhalothrin 2.5 EC (Lambda cyhalothrin), karate (Lambda-cyhalothrin), round-up (glyphosate), Master (Bifenthrin) and Dursban (Chlorpyrifos-ethyl) (Mattah et al. 2015; Quansah et al. 2020). However, previous studies have reported abuse of pesticide use in vegetable farming in Ghana (Amoako et al. 2012; Afari-Sefa et al. 2015; Amoabeng et al. 2017) and other African countries (Staudacher et al. 2020; Mergia et al. 2021). Some farmers do not use the recommended dose of pesticides, follow withholding periods between pesticide application and harvesting, mixing of different pesticides together for use and indiscriminate disposal of pesticide containers on the farms or into surrounding water bodies used for irrigation (Fianko et al. 2011; Afari-Sefa et al. 2015; Amoabeng et al. 2017).

The abuse of pesticides in farming can lead to increased concentrations of pesticide residues on vegetables. Residues of pesticides can persist in vegetables and get ingested by consumers. Some pesticides have been associated with several diseases in humans including cancers, birth defects and reproductive disorders

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(Mostafalou and Abdollahi 2013; Kim et al. 2017). Pesticides can also persist in the soil and run off into surrounding surface and groundwater bodies that may be used for irrigation (Aktar et al. 2009). The use of water bodies contaminated with pesticides for irrigation could contribute to the contamination of the produce with pesticide residues (Pradhan et al. 2022).

Washing and processing of fresh produce such as peeling, blanching and canning may reduce pesticide residue levels, but cannot completely remove the residues from the vegetables, thus they may have the potential to cause adverse health effects to consumers (Keikotlhaile et al. 2010; Bonnechère et al. 2012). The objective of this study was to determine the occurrence and concentration of pesticide residues in irrigation waters and on leafy green vegetables grown in Accra, Ghana.

## Materials and methods

### Sample collection

Samples of two exotic, lettuce (*Lactuca sativa*) and cabbage (*Brassica oleracea*) and four indigenous Ghanaian (African spinach (*Amaranthus* sp.), African eggplant leaves (*Solanum macrocarpon*), roselle leaves (*Hibiscus sabdariffa*) and jute leaves (*Corchorus olitorius*) leafy green vegetables ($n = 34$) were collected in duplicate from 15 farms in 10 different farming areas in the Accra Metropolis district of Ghana from March 2016 to September 2016 (Table 1). Approximately 1 kg of each vegetable sample was collected from the farmers who cultivated them and were willing to participate in the study. Additionally, about 2 L of samples of irrigation water (river/drain, shallow well and waste drains; $n = 23$) used in the 10 farming areas in this study area were analysed. Collected leafy green vegetables and irrigation water were kept in a car cooler (Rubbermaid; Newell Brands Inc, Atlanta, GA, USA) with ice packs (VWR, Lutterworth, UK) and transported to the pesticide residue laboratory of the Ghana Standard Authority, which is accredited for pesticides analysis in accordance to ISO/IEC 17025:2005 by the German accreditation body (Deutsche Akkreditierungsstelle GmbH, DAKKS) in Accra, for analysis.

### Extraction and clean-up of vegetables

The QuEChERS method was used with modifications (Blankson et al. 2016; Choubbane et al. 2022; Luo et al. 2023). The samples were homogenised with a Molino Foss homogeniser HM 294-ICSA (Valencia, Spain), and 10 g of comminuted samples were weighed into 50 ml centrifuge tubes. Acetonitrile (10 ml) was added and vortexed for 1 min. A mixture of magnesium sulphate anhydrous (4 g), sodium chloride (1 g), sodium citrate dihydrate (1 g) and sodium hydrogen citrate (0.5 g) were added and vortexed for 1 min. The samples were then centrifuged at 2,700 *g* for 5 min. About 6 ml of the supernatant was transferred into another centrifuge tube containing 150 mg of primary secondary amide and 900 mg of magnesium sulphate, shaken for 30 sec and centrifuged at 2,000 *g* for 5 min. Later, 4 ml of the supernatant was transferred into a round bottom flask and 40 ml of 5% formic acid solution in acetonitrile was added and concentrated to dryness with a rotary evaporator (below 40°C). After evaporation, 1.0 ml ethyl acetate was added for reconstitution prior to quantitation by GC. A matrix blank and reagent blank were also analysed.

### Extraction and clean-up of irrigation water

The method described Fosu-Mensah et al. (2016) was used with modifications. The water samples were filtered through Whatman filter paper 42 to remove debris and solid particles. About 1 L of the filtered water was transferred into a separating funnel and 30 ml of saturated sodium chloride solution

**Table 1.** Number of leafy green vegetable samples collected from individual farming areas in Accra metropolis, Ghana.

| | Number of leafy green vegetables collected | | | | | | Number of irrigation waters collected | | |
|---|---|---|---|---|---|---|---|---|---|
| Source | *Amaranthus* | Cabbage | *C. olitorius* | *H. sabdariffa* | Lettuce | *S. macrocarpon* | River/drain | Shallow well | Waste drain |
| FA 1 | 2 | 0 | 2 | 0 | 4 | 0 | 2 | 0 | 0 |
| FA 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| FA 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 |
| FA 4 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 |
| FA 5 | 0 | 0 | 2 | 0 | 2 | 1 | 0 | 2 | 2 |
| FA 6 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| FA 7 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 2 |
| FA 8 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| FA 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FA 10 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 |
| FA 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FA 12 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 |
| Total | 8 | 3 | 4 | 2 | 14 | 3 | 4 | 11 | 8 |

added. The water samples were partitioned with 100 ml of dichloromethane by shaking the separating funnel vigorously for 2–3 min and releasing the pressure intermittently. The layers were allowed to separate and after complete separation, the organic phase was drained. The extraction procedure was repeated three times. All three organic phases were combined and passed through anhydrous sodium sulphate and concentrated to 2 ml using a rotary vacuum evaporator.

Column chromatography was used to clean up the extracts with a conditioned Silica cartridge which had a 0.3 g layer of sodium sulphate and 10 ml dichloromethane on top. The concentrated water extracts were loaded onto the cartridge. The column was eluted with 20 ml dichloromethane and the eluent was collected and concentrated just to dryness using the rotary evaporator below 40°C. The dry sample extracts were then re-dissolved in 1 ml ethyl acetate prior to quantitation by GC.

### Organochlorine and synthetic pyrethroids analysis

A Varian gas chromatograph CP-3800 (Varian Inc, Walnut Creek, CA) equipped with $^{63}$ Ni electron capture detector (ECD) and pulse flame photometric detector (PFPD) was used to analyse organochlorine (OC) and synthetic pyrethroids (SP) pesticide residues. The following GC parameters were used for analysis: capillary column (Agilent J&W GC columns, Santa Clara, CA, USA) coated with VF-5 ms (30 m + 10 EZ Guard, 0.25 mm, 0.25 µm film thickness). Nitrogen gas was used as carrier gas and make-up gas at a flow rate of 1.0 and 29 ml/min, respectively. The temperature of the injector operating in splitless mode was held at 270°C and ECD was set at 300°C. The column oven temperature was programmed at 70°C for 2 min and increased steadily at a rate of 25°C min$^{-1}$ to 180°C and increased at 5°C min$^{-1}$ up to 300°C. The injection volume of the GC was 1.0 µl. A Varian Saturn GC (CP-3800 2200 MS/MS) mass spectrometer was used to confirm the residues detected by GC analysis.

The organochlorine pesticide residues tested were lindane, dieldrin, p,p'-DDT, beta-HCH, delta-HCH, p, p'-DDD, p,p'-DDE, aldrin, endrin, heptachlor, gamma-chlordane, alpha-endosulfan, beta-endosulfan, endosulfan sulphate and methoxychlor. Synthetic pyrethroids pesticide residues tested include allethrin, lambda-cyhalothrin, cypermethrin, deltamethrin, fenvalerate, bifenthrin, cyfluthrin, fenpropathrin and permethrin (Dr. Ehrenstorfer GmbH, Augsburg, Germany).

### Organophosphorus pesticides analysis

A Varian gas chromatograph CP-3800 equipped with a pulse flame photometric detector (PFPD) was used to analyse organophosphorus pesticide residues. The GC parameters used for analysis was a capillary column (Agilent J&W GC columns, Santa Clara, CA, USA) coated with VF-1701 ms (30 m, 0.25 mm, 0.25 mm film thickness). Nitrogen gas was used as carrier gas at a flow rate of 2.0 ml/min with Air 1, Air 2 and $H_2$ flow rate of 17, 10 and 14 ml/min respectively. The temperature of the injector operating in splitless mode was held at 270°C and PFPD was set at 280°C. The column oven temperature was programmed at 70°C for 2 min and increased steadily at a rate of 25°C min$^{-1}$ to 200°C min$^{-1}$ and increased at 20°C min$^{-1}$ up to 250°C. The injection volume of the GC was 2.0 µl. A Varian Saturn GC (CP-3800 2200 MS/MS) was used to confirm residues detected by GC analysis.

Organophosphorus pesticide residues tested include chlorpyrifos, methamidophos, phorate, diazinon, fonofos, parathion, chlorfenvinphos, malathion, fenitrothion, profenofos, ethoprophos, dimethoate and pirimiphos-methyl.

### Pesticide standard solutions

Pesticide standards (Dr. Ehrenstorfer GmbH, Augsburg, Germany) were dissolved in ethyl acetate to make a 1 mg/ml pesticide spike solution. The spike solution was added to the matrix after the sample for extraction was weighed. The matrix blank was fortified with pesticide solutions to achieve 0.05 mg/kg and allowed to stand for 10 min to enhance pesticide interaction with the matrix.

The calibration standards were made by diluting pesticide solutions with ethyl acetate to make concentrations of 0.005, 0.01, 0.02, 0.05, 0.1, 0.50 and 1.0 mg/ml. The limit of detection (LOD) for organochlorines, organophosphorus and synthetic pyrethroids pesticide residues in the vegetables was 0.005, 0.010 and 0.010 mg/kg respectively. The LOD for organochlorines, organophosphorus and synthetic pyrethroids pesticide residues in water samples was 0.01 µg/L, 0.05 µg/L and 0.05 µg/L respectively.

LOD was calculated using the formula LOD = 3.3 (SD/S), where SD is the standard deviation of the response and S is the slope of the calibration curve. Spiked samples and matrix blank samples were included in every analytical batch as quality controls. No organochlorine, organophosphorus, or synthetic pyrethroid pesticides were detected in the blank of each extraction procedure.

## Results and discussion

Pesticide residues were detected in 50% (17/34) of the vegetables sampled from 9 out of the 10 farming areas involved in the study (Table 2). This observation could be attributed to the abuse of pesticides in vegetable farming reported in previous studies in Ghana (Fianko et al. 2011; Afari-Sefa et al. 2015; Amoabeng et al. 2017). The findings of the study are similar to the incidence of 52% of detected pesticide residues in vegetables sold in Accra, Ghana (Blankson et al. 2016), but these incidences were lower compared to the 100% (16/16) of leafy vegetables and ready-to-eat vegetables sampled from farms and food vendors in the Ashanti region, Ghana (Akomea-Frempong et al. 2017), 71% of lettuce sampled in Colombia (Barbosa et al. 2023), 92.1% of the leafy and non-leafy vegetables sampled in China (Yu et al. 2016) and 65% of leafy vegetables tested in Chile (Elgueta et al. 2017).

None of the organochlorine pesticide residues analysed in this study was detected in the leafy vegetables. This observation could be due to the enforcement of the ban on the use of persistent organic pollutants such as organochlorine pesticides over two decades in most countries including Ghana after the adoption and entry into force of the Stockholm Convention in 2001 and 2003, respectively (Secretariat of the Stockholm Convention 2012; Bruce-Vanderpuije et al. 2019). These pollutants were banned due to their high persistence and bioaccumulation potential in the food web and the adverse effects they can pose to human health and the environment (Kleanthi et al. 2008; Singh 2016). The absence of organochlorine residues in the vegetables sampled in this study is in contrast with a previous study by Amoah et al. (2006) where organochlorine residues (endosulfan, lindane and dichlorodiphenyltrichloroethane (DDT)) were detected in lettuce in Ghana. Furthermore, Bempah et al. (2012) detected metabolites of DDT, lindane, endrin, dieldrin and heptachlor in 72% of the vegetables sampled in Ghana despite the ban on the use of organochlorine pesticides at their study time.

Five organophosphorus (chlorpyrifos, diazinon, dimethoate, malathion, pirimiphos-methyl) and six synthetic pyrethroids pesticide residues (bifenthrin, cypermethrin, deltamethrin, fenvalerate, lambda-cyhalothrin, permethrin) were detected in the vegetables (Table 2). Chlorpyrifos (26.5%) and deltamethrin (20.6%) were the most detected organophosphorus pesticide residues in the vegetable samples. Cypermethrin (14.7%) and lambda-cyhalothrin (14.7%) were synthetic pyrethroids pesticide residues detected in the vegetable samples. The high incidence of chlorpyrifos residues in the vegetables is similar to reports of chlorpyrifos being the most detected pesticide residue in 35 out of 155 non-leafy vegetable samples collected and could be attributed to the high usage of chlorpyrifos-based pesticides in vegetable production in Ghana (Blankson et al. 2016). Sapbamrer and Hongsibsong (2014) also reported that chlorpyrifos was the most detected pesticide in 14 out of 84 leafy and non-leafy vegetables analysed in Thailand.

About 26.5% of the vegetables examined in this study (four lettuces, two *S. macrocarpon*, one of *Amaranthus* sp., *H. sabdariffa and C. olitorius*) had pesticide residues above the adopted EU maximum residue limits (MRLs) used. It was observed that 55.6% of chlorpyrifos (5/9), 42.9% of deltamethrin (3/7) and 80% of lambda-cyhalothrin (4/5) detected in the vegetables exceeded their MRLs. This observation could be attributed to inappropriate pesticide use practices such as 1). applying the pesticide at the sight of a pest and/or disease, 2). according to the crop calendar where insects may not be present at levels that warrant control and 3). not abiding by waiting time after the last spray before harvesting of produce (Afari-Sefa et al. 2015; Amoabeng et al. 2017). The prevalence of pesticide residue in vegetables above their MRLs in previous studies reported a prevalence of 21% in vegetables in Ghana (Blankson et al. 2016), 23% in leafy and non-leafy vegetables in China (Yu et al. 2016), 29% in lettuce in Colombia (Miranda et al. 2016) and 27% in leafy vegetables in Chile (Elgueta et al. 2017).

Deltamethrin was the only pesticide residue detected in 38% (3/8) of Amaranthus sampled from three farming areas. Five organophosphorus pesticide residues (chlorpyrifos, diazinon, dimethoate, malathion and pirimiphos-methyl) were detected in one (33%) cabbage sampled from FA 2 (Table 3). This could be attributed to challenges of pest control and the ineffectiveness of most pesticides employed in cabbage cultivation thus some farmers resort to frequent application of different pesticides to manage pests (Badii et al. 2013; Afari-Sefa et al. 2015; Amoabeng et al. 2017). Chlorpyrifos, cypermethrin, deltamethrin, lambda-cyhalothrin and permethrin were detected in 75% (3/4) of *C. olitorius* sampled from two farming areas. Chlorpyrifos and lambda-cyhalothrin were detected in all (2/2) *H. sabdariffa* sampled from FA 3. Chlorpyrifos, dimethoate, cypermethrin, deltamethrin and fenvalerate were detected in 42.9% (6/14) of lettuce sampled from five farming areas. The presence of five pesticide residues in lettuce from five farming areas shows the extensive usage of pesticides in lettuce farming. Diazinon, cypermethrin, deltamethrin and lambda-cyhalothrin were detected in 66.7% (2/3) of *S. macrocarpon* sampled from two farming areas (Table 3).

**Table 2.** Organophosphorus pesticide residues in the leafy green vegetables.

| | | organophosphorus pesticide residues | | | | | synthetic pyrethroids pesticide residues | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Chlorpyrifos | Diazinon | Dimethoate | Malathion | Pirimiphos-methyl | Bifenthrin | Cypermethrin | Deltamethrin | Fenvalerate | Lambda-cyhalothirn | Permethrin |
| Faming Area | Leafy green vegetable | mg/kg | | | | | mg/kg | | | | | |
| FA 1 | *Amaranthus sp.* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.022 | <LOD | <LOD | <LOD |
| FA 1 | *Amaranthus sp.* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 1 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 1 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 1 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 1 | Lettuce | 0.018* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 1 | *C. olitorius* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 1 | *C. olitorius* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.032 |
| FA 2 | Cabbage | 0.010 | <0.010 | <0.010 | 0.010 | <.010 | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 2 | *Amaranthus sp* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 2 | *Amaranthus sp* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 3 | *H. sabdariffa* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.365* | <LOD |
| FA 3 | *H. sabdariffa* | 0.022* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.625* | <LOD |
| FA 4 | Lettuce | 0.041* | <LOD | <LOD | <LOD | <LOD | <LOD | 0.025 | <LOD | <LOD | <LOD | <LOD |
| FA 4 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 5 | *C. olitorius* | <0.010 | <LOD | <LOD | <LOD | <LOD | <LOD | 0.020 | 0.010 | <LOD | 0.210* | <LOD |
| FA 5 | *C. olitorius* | 0.040* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.415* | <LOD |
| FA 5 | Lettuce | 0.010 | <LOD | 0.095* | <LOD | <LOD | <LOD | 0.025 | 0.010 | <LOD | <LOD | <LOD |
| FA 5 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 5 | *S. macrocarpon* | <LOD | <0.010 | <LOD | <LOD | <LOD | <LOD | 0.12 | 0.020 | <LOD | 0.010 | <LOD |
| FA 6 | *Amaranthus sp.* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 6 | *Amaranthus sp.* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.010 | <LOD | <LOD | <LOD |
| FA 6 | *S. macrocarpon* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 6 | *S. macrocarpon* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.020 | <LOD | <LOD | <LOD |
| FA 7 | *Amaranthus sp.* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 7 | *Amaranthus sp.* | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | 0.010 | <LOD | <LOD | <LOD |
| FA 7 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 7 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 8 | Cabbage | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 8 | Cabbage | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 10 | Lettuce | 0.010 | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |
| FA 10 | Lettuce | 0.340* | <LOD | <LOD | <LOD | <LOD | <LOD | 0.085 | <LOD | <LOD | <LOD | <LOD |
| FA 12 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | 0.01 | <LOD | <LOD | 0.01 | <LOD | <LOD |
| FA 12 | Lettuce | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD | <LOD |

*Above the EU MRL.

**Table 3.** Occurence of pesticide residues in the leafy green vegetables.

| | Amaranthus | Cabbage | *C. olitorius* | *H. sabdariffa* | Lettuce | *S. macrocarpon* | Total |
|---|---|---|---|---|---|---|---|
| Chlorpyrifos | 0 | 1 | 2 | 1 | 5 | 0 | 9 |
| Diazinon | 0 | 1 | 0 | 0 | 0 | 1 | 2 |
| Dimethoate | 0 | 1 | 0 | 0 | 1 | 0 | 2 |
| Malathion | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Pirimiphos-methyl | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Bifenthrin | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Cypermethrin | 0 | 0 | 1 | 0 | 3 | 1 | 5 |
| Deltamethrin | 3 | 0 | 1 | 0 | 1 | 2 | 7 |
| Fenvalerate | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Lambda-cyhalothirn | 0 | 0 | 2 | 2 | 0 | 1 | 5 |
| Permethrin | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Total | 3 | 5 | 7 | 3 | 12 | 5 | 35 |

**Table 4.** Concentration of organophosphorus and synthetic pyrethroids pesticide residues in the irrigation water.

| Farming area | Irrigation water | organophosphorus Chlorpyrifos (μg/L) | synthetic pyrethroids Permethrin (μg/L) |
|---|---|---|---|
| FA 1 | River/drain | <LOD | <LOD |
| FA 1 | River/drain | 0.12 | <LOD |
| FA 2 | Shallow well | <LOD | <LOD |
| FA 2 | Shallow well | <LOD | <LOD |
| FA 3 | Shallow well | <LOD | <LOD |
| FA 3 | Shallow well | <LOD | <LOD |
| FA 4 | River/drain | 0.45 | <LOD |
| FA 4 | River/drain | 0.7 | <LOD |
| FA 5 | shallow well | <LOD | <LOD |
| FA 5 | shallow well | <LOD | <LOD |
| FA 5 | Waste drain | <LOD | <LOD |
| FA 5 | Waste drain | <LOD | <LOD |
| FA 6 | Waste drain | 0.43 | 0.12 |
| FA 6 | Waste drain | 0.26 | 0.12 |
| FA 7 | Shallow well | <LOD | <LOD |
| FA 7 | Waste drain | 0.17 | <LOD |
| FA 7 | Waste drain | 0.12 | <LOD |
| FA 8 | Waste drain | 0.11 | <LOD |
| FA 8 | Waste drain | 0.13 | <LOD |
| FA 10 | Shallow well | 0.09 | <LOD |
| FA 10 | Shallow well | 0.15 | <LOD |
| FA 12 | Shallow well | <LOD | <LOD |
| FA 12 | Shallow well | 0.23 | <LOD |

Pesticide residues were detected in 52% (12/23) of the irrigation water sampled in 6 out of the 10 farming areas used in the study (Table 4). None of the organochlorine pesticides was detected in the samples of irrigation water. However, one organophosphorus (chlorpyrifos) and one synthetic pyrethroid (permethrin) pesticide residue were detected in the irrigation water samples (Table 4). Chlorpyrifos was detected in irrigation water samples from river/drain (3/4) sampled from two farming areas, shallow wells (3/11) from two farming areas and waste drains (6/8) from three farming areas. Permethrin was only detected in water samples from waste drains in FA6 (2/8). The high prevalence of chlorpyrifos in all types of irrigation water samples could be due to the extensive usage of chlorpyrifos-based pesticides in vegetable farming areas and improper disposal of empty pesticide containers near water bodies (Afari-Sefa et al. 2015).

It was observed that most of the pesticide residues detected in the vegetables were not detected in the irrigation water used in those farming areas, however, chlorpyrifos was detected in three lettuce samples from two farming areas (FA 4 and FA 10) and also in irrigation water used in those farming areas. This observation could indicate that irrigation water may not be a major contamination source of pesticide residues in vegetables and the presence of pesticide residues in irrigation water could be due to poor management of pesticides such as indiscriminate disposal of empty pesticide containers and wastewater from the knapsack sprayer on the farms and close to water bodies (Afari-Sefa et al. 2015).

Production of leafy green vegetables with pesticide residues above MRLs as observed in the study can lead to high production costs due to the purchase of pesticides used for vegetable production. The presence of high residue in these vegetables will also hinder access to the export market for improved revenue (Lengai et al. 2022). Consumption of such leafy green vegetables contaminated with high levels of pesticide residues over long-term can lead to increasing concentrations of the residues in body organs and cause chronic diseases such as cancer, asthma, birth defects, reproductive disorders, cardiac disease, diabetes (Mostafalou and Abdollahi 2013; Kim et al. 2017; Kalyabina et al. 2021). The risk of pesticide residues through residues in foods must be assessed and adequate protection measures recommended for implementation (WHO 2023). The results of such risk assessments should be shared with regulatory agencies for risk communication to all stake holders. Furthermore, deliberate efforts must be made by regulators to educate farmers and value chain actors on good agricultural practices as well as the risk of long-term exposure to pesticides through the diet.

## Conclusion

Pesticide residues were detected in 50% of the vegetables sampled in the study and about 26.5% of these residues were above their MRLs in the vegetables. Pesticide residues were detected in 52% of samples of the irrigation water in the study. Chlorpyrifos was the most detected pesticide residue in the vegetables and irrigation water. Farmers should be trained on the efficient use of pesticides in vegetable farming and comply with appropriate measures associated with their use to improve food safety.

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