Mbatchou *et al.*
CABI Agriculture and Bioscience (2024) 5:51
https://doi.org/10.1186/s43170-024-00252-z

CABI Agriculture and Bioscience

RESEARCH

Open Access

Effects of pesticide residues on the growth and yield of vegetables at Navrongo of Ghana

Valentine Chi Mbatchou[1], Osman Daddy Yunusah[1] and Umar Farouk Iddrisu[1*]

Abstract

Background The constant use of pesticides on farmlands is a source of food poison and potential cause of disease to humans in most parts of Africa. The lack of in-depth knowledge on the choices of use of the pesticides and their applications by most farmers in our African communities is a key to unsafe food and unhealthy living. Furthermore, the impact of some of these pesticides on the growth and yield of vegetable crops is largely unexplored. The present research was conducted in the Tono Irrigation Dam area of Navrongo, Ghana, where vegetable cultivation holds substantial economic importance making it a critical aspect of the local economy. In this study, we identified prevalent pesticides used in Navrongo's vegetable cultivation, quantified pesticide residues present in selected vegetables grown, and assessed the impact of the pesticides on the vegetable crops' growth and yields.

Methods Thirty vegetable farmers at the Tono Irrigation Dam Area, Navrongo were randomly selected, and interviewed face to face. Questionnaires were also employed for data acquisition. Vegetables were sampled by dividing the farmland of each of the vegetable types in to three equal portions, and from each of the three portions, one sample was collected which was then put together with the other two samples as one. The samples were packed in zip-lock bags and kept at a cold temperature (– 20 ℃) before being transferred to the laboratory where they were thawed, homogenized and then subjected to extraction. The extract obtained was subjected to a clean-up process and then analyzed on a GC–MS instrument for pesticide detection and quantification.

Results The interview revealed number of years of farmers' engagemrent in vegetable cultivation from one to ten, and identified four key vegetable varieties grown by the farmers: *Capsicum annuum* (pepper), *Abelmoschus esculentus* (okra), *Solanum aethiopicum* (garden egg) and *Solanum lycopersicum* (tomato). The data acquired gave identities or names of eight pesticides that are applied on the cultivated vegetables or farmlands by the farmers, and a decision on the vegetables selected for analysis in this study. Furthermore, the study revealed dichlorodiphenyltrichloroethane (DDT), k-optimal, lindane, and lambda-cyhalothrin to be among the pesticides in use, with DDT being a non-degradable, and the most widely applied pesticide. Notably, the DDT, lindane, and hexachlorocyclohexane, residues exceeded safety limits set by the European Commission in pepper, garden egg and okra. Unfortunately, banned pesticides such as heptachlor and aldrin were detected in the cultivated vegetables. More alarmingly, the commonly used DDT and lambda-cyhalothrin in the vegetable cultivation were found to hinder seed germination and seedling vigor in an investigation.

Conclusions The DDT, lindane, and hexachlorocyclohexane, residues detected in the pepper, garden egg and okra samples that exceeded safety limits render these vegetables unsafe for human consumption. The banned heptachlor and aldrin detected in the vegetables indicate long-lasting environmental contamination. The commonly used DDT

*Correspondence:
Umar Farouk Iddrisu
umar.iddrisu@uds.edu.gh
Full list of author information is available at the end of the article

and lambda-cyhalothrin in the vegetable cultivation found to hinder seed germination and seedling vigor, indicate their non-degradability and substantial growth impediments. This present study therefore underscores the urgent need for enhanced safety measures and informs pesticide practices to safeguard both crops and public health in the district. We recommend further research be conducted to assess the potential health implications associated with the cultivation and consumption of vegetables in Navrongo, Ghana.

Keywords Ghana, Navrongo, Vegetables, Pesticides, Residues, Growth, Yield, Germination seedling vigor

Background

Vegetables are an essential part of human diets, providing essential nutrients and vitamins. Navrongo, is a town in the Upper East Region of Ghana where vegetables are grown extensively, and they play a significant role in the local economy (Tudi et al. 2021). Insect and plant pests attack can cause significant damage to vegetable crops, leading to reduced growth, yields and economic losses. To combat these pests, farmers often use pesticides. Pesticides can be classified on the basis of target pests and chemical identity (Tudi et al. 2021). On the basis of target pests, pesticides can be classified as insecticides, herbicides, fungicides, and rodenticides whereas on the basis of chemical identity, they are classified as organochlorines, organophosphates, pyrethroids and carbamates (Tudi et al. 2021).

However, the use of pesticides can have negative effects on the environment and human health. In Navrongo, Ghana, a semi-arid town characterized by a low-input rain-fed smallholder agricultural system, major vegetables are peppers, garden eggs, tomatoes, and okra. These crops are vital to the local economy and food security but are susceptible to various insect and plant pests (Aniah et al. 2021). The high demand for pesticide application in vegetable farming in Ghana is a result of widespread problems of insect and plant pests, and diseases (Aniah et al. 2021). Common pesticides used in the region include organophosphates such as dimethoate and chlorpyrifos (Donkor et al. 2016).

Recent research has shown mixed evidence on the risks of pesticide residue on produce (Sharma et al. 2023). Pesticides have played a vital role in increasing plant growth, stabilizing yield and reducing crop losses due to pests and diseases (Sharma et al. 2023), but their misuse can lead to health risks. In developing countries like Ghana, higher proportions of pesticide poisonings occur due to inadequate protective clothing, poor labeling of pesticides, illiteracy, and insufficient knowledge of pesticide application of concentration in vegetables.

Despite the regulations governing pesticide use in Ghana, there is a gap in ensuring the safety of food due to pesticide residues (Onwona Kwakye et al. 2019). This study aims to bridge this gap by analyzing pesticide residues in locally consumed vegetables in Navrongo, Ghana. The objectives were to monitor and identify the most commonly used pesticides in vegetable crops in Navrongo, Ghana, and provide updated information about the effects of these pesticides on the growth and yield of vegetables.

This study is justified by the need for continuous monitoring of pesticide use in agriculture due to its potential impact on human health and the environment. It will contribute to the body of knowledge on pesticide residues in vegetables and provide valuable data for policymakers in implementing effective regulations on pesticide use.

Methods

Field survey

A survey was conducted at Tono Irrigation Dam Area from April to September 2022. Questionnaires were employed to obtain information on years of farmers' engagement in vegetable cultivation, types of vegetables cultivated, number of farmers engaged in cultivation of a particular type of vegetable, reasons for cultivation of a particular type of vegetable, names of pesticides used on the vegetables, why the use of a particular type of pesticide or mixture of pesticides, and why a change in use of a particular type of pesticide at Tono Irrigation Dam Area, Navrongo, Ghana. The data obtained was analyzed with the view to making a decision on the most commonly or widely used pesticides, and grown vegetables by the farmers to be selected for this study. In total, 30 vegetable farmers were randomly selected and interviewed after a consent was sought from them. The Tono Irrigation Dam Area is located 3 km South-West of Navrongo, along the Navrongo-Sandema road. It is found within longitudes 1° 4′W and 1° 10′W, and latitudes 10° 44′N and 10° 54′N. The place covered by the survey is Wuru, and the total annual rainfall of the entire Tono Irrigation Dam Area is between 950 and 1200 mm which starts in May, continues to its peak in August and then drops drastically in October. The rainfall is proceeded by a long dry period from November to April in which there is very little rainfall. Average monthly temperatures reduce to 26 °C in August and September, and remain high throughout the year at Navrongo. The hottest months, March and April record 32 °C. December or January records absolute minimum temperatures of about 16 °C, whereas March and April record an absolute maximum temperature of 35 °C (Adams et al. 2014) (see Fig. 1).

Sampling and sample collection

To determine the residues of different pesticides in *Capsicum annuum* (pepper), marketable pepper samples from the farm sites of farmers interviewed in the field survey were used. Sampling was carried out when the farmers were harvesting their vegetables for sale. The farm site of each farmer was divided in to three equal portions, and from each of the three portions, one sample was collected which was then put together with the other two samples as one. In all, a total of seventeen (17) pepper samples was collected from the farm sites of seventeen (17) farmers. The samples collected were packed in zip-lock bags, stored at a cold temperature of − 20 °C in an ice chest, containing ice blocks before being transferred to the laboratory for analysis. The same procedure was applied to *Solanum aethiopicum* (garden egg-5 samples) and *Abelmoschus esculentus* (okra-6 samples), from the farm sites of five (5) and six (6) farmers respectively.

Laboratory examination of vegetables for pesticide residue

Sample preparation and analysis

Extraction process

The pepper, garden egg and okra samples were stored in a refrigerator at − 20 ℃. After spending seventy-two (72) hours, the samples were taken from the refrigerator, thawed and homogenized using a blender. Ten (10) grammes each of the homogenized samples were transferred into three different extraction flasks. Two point five (2.5) grammes of sodium hydrogen carbonate ($NAHCO_3$, Sigma-Aldrich Chemicals Ltd, St. Louis, Missouri, USA) were added to each of the weighed sample. Fifty milliliters (50 ml) of n-hexane–acetone (n-hexane and acetone, Merck KGaA, Darmstadt, Germany) solvent mixture (3:1) were added to each of the sample for extraction to take place. The resultant mixture was vortexed for one (1) minute and then centrifuged on an ultrasonic sonicator (Ependorf centrifuge, Germany) for five (5) minutes at 3000 rpm. Five milliliters (5 ml) of the upper layer of the centrifuged mixture were transferred into a round bottom flask, and contents of the flask were

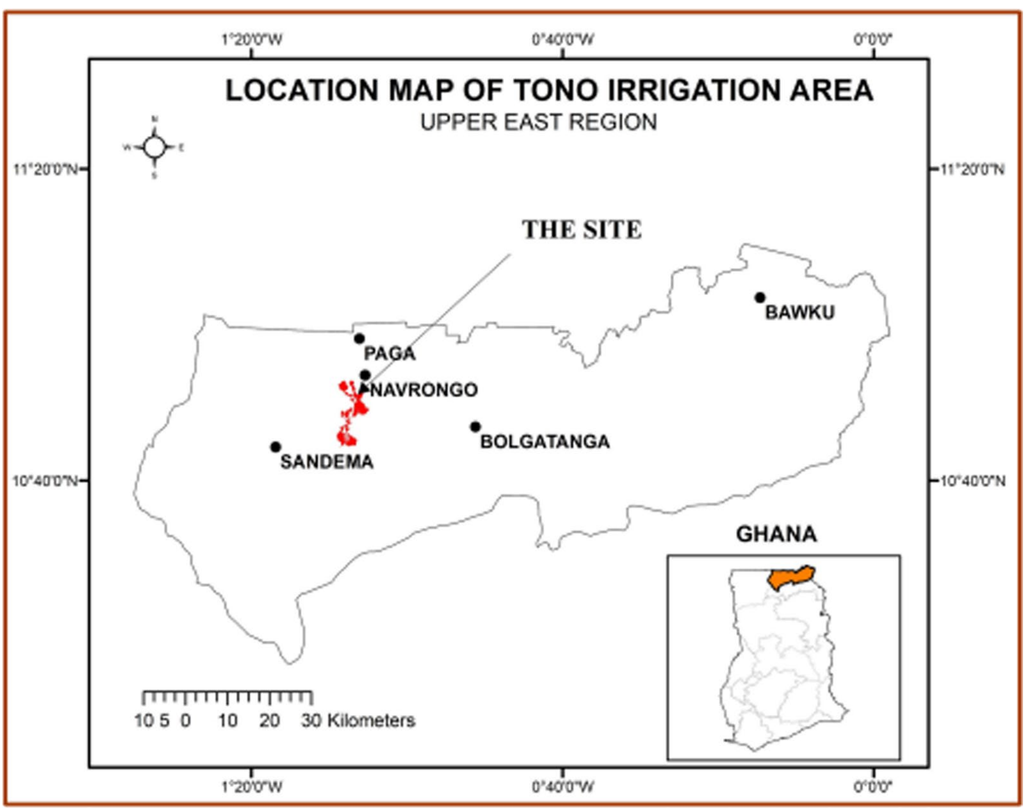

Fig. 1 Location of Tono Irrigation Dam Area, Navrongo, Ghana (Adams et al. 2014)

then evaporated to dryness on a rotary evaporator (Heidolph instruments GmbH and Co. KG, Germany) at 40 ℃ (Ghana Atomic Energy Commission, Accra-Ghana).

Clean up procedure

The extract from the extraction process was passed through a clean-up procedure using a column packed with 4 grammes of silica gel (ASTM), 2 grammes of sodium sulphate (Na_2SO_4, Sigma-Aldrich Chemicals Ltd, St. Louis, Missouri, USA) and 1 gramme of activated charcoal (Water Corp., Milford, MA, USA), with the outlet of the column having a cotton to reduce solvent flow. The packed and clamped column was conditioned with 10 ml of n-hexane–acetone solvent mixture (3: 1), and the extract was then delivered into a receiving flask beneath the column. The column was eluted with 10 ml of n-hexane, and further with another 10 ml of n-hexane–acetone solvent mixture (3: 1). The eluent was concentrated on a rotary evaporator under reduced pressure at 40 ℃, and the eluate was analyzed on a GC–MS instrument (Shimadzu, Japan) for pesticide residue detection after it had been dissolved in ethyl acetate (Ghana Atomic Energy Commission, Accra-Ghana).

GC–MS analysis

Extracted and cleaned-up vegetable samples of the pepper, garden egg and okra were analyzed in a gas chromatograph (Varian CP-3800 with Combi PAL auto-sampler) coupled with a mass spectrophotometer (GC–MS). The GC was fitted with an analytical column, 30 m + 10 m EZ Guard × 0.25 mm id fused silica capillary coated with VF-5 ms (0.25 μm film). Vials containing samples for analyzes were interspersed with vials of pesticide standards (EPA, Fort Meade, MD, USA) on the auto-sampler. The pesticides and residues of interest in the vegetable samples were identified by comparing their retention times with those of the standards, and quantification was carried out by extrapolation of calibration curves. The GC–MS was run in the injector mode, splitless with injector temperature 270 °C, oven temperature was programmed at 70 °C for 2 min, and increased to 180 °C at a rate of 25 °C per minute, then from 180˚C the temperature of the electron capture detector was set at 300 °C. Nitrogen was used as the carrier gas at a flow rate of 1 ml per minute constant flow, with a make-up of 29 ml per minute. Quality assurance measures carried out included contamination control procedures, monitoring of instruments, detector response and linearity, analysis of blanks, recovery of standards, re-calibration standards run to check the validity of the calibration curves. The analytical methods were validated by pesticide recovery experiments using extracts. Reference materials for pesticide residues were obtained from NIST.

Assessment of pesticide effect on plant growth

Three groups of pepper plants, consisting of 13 to 15 members each were cultivated at the study area. The three groups were labelled as A, B and C, respectively. The pepper plants in group A were grown without application of any pesticide on them. Dichlorodiphenyltrichloroethane (15 ml/ 15 L of water) and lambdacyahalothrin (10 ml/15 L of water) were applied to the pepper plants in group B, whereas the pepper plants in group C were treated with dichlorodiphenyltrichloroethane (30 ml/15 L of water) and lambdacyahalothrin (20 ml/15 L of water) in the same manner as farmers at the Tono Irrigation area do to their crops. The seeds from the pepper were obtained after harvest and labelled as seed lot A, seed lot B and seed lot C for pepper groups A, B and C, respectively. Seed germination and seedling vigor analyses in the form of growth test were carried out. This same procedure was undertaken for garden egg and okra.

Growth test

One hundred pepper seeds each from seed lots A, B, and C, respectively were planted in trays containing soil for germination. The number of seedlings emerging daily were counted till the time germination was complete. A seed is considered germinated when the radicle (0.6 cm) is protruded. The same was done for okra and garden egg. After germination, germination percentage for pepper, garden egg and okra were recorded respectively alongside the radicle length, plumule length and seedling vigor.

Thereafter, the germination percentage was computed by using the following formula (ISTA, 1976):

$$\text{Germination percentage} = (\text{Number of germinated seeds}) / (\text{Number of seeds cultivated}) \times 100$$

The seedling vigor was also computed using the formula:

$$\text{Seedling vigor} = [\text{Seedling length (cm)} \times \text{Germination percentage (\%)}]$$

Results

Field survey

Percentages of farmers who are engaged in vegetable cultivation at the Tono Irrigation Dam Area, Navrongo, Ghana for 5, 2, 4, 6, 8 and 10 years respectively,

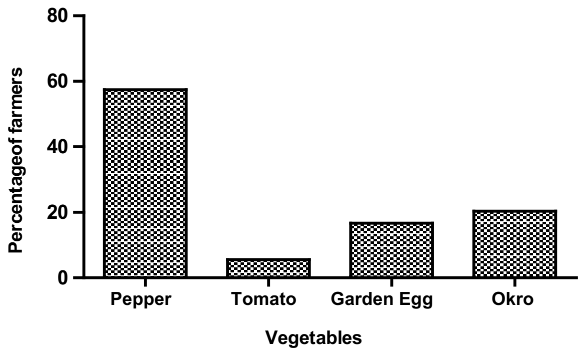

Fig. 2 Farmers (%) involvement in to cultivation of vegetables at Tono Irrigation Dam Area, Navrongo

significantly differ from percentages of farmers who are engaged in the cultivation for 3 and 7 years ($P < 0.05$, t-test). This clearly indicates that farmers who are engaged in the cultivation for 5, 2, 4, 6, 8 and 10 years are more than those who are engaged for 3 and 7 years.

For the 30 farmers interviewed, 56.6%, 6.6%, 16.6% and 20% were in to pepper, tomato, garden egg and okro cultivation, respectively (Fig. 2). The percentage of farmers involved in the pepper cultivation greatly differed from those involved in the cultivation of tomato, garden egg and okro ($P < 0.05$, t-test).

For the 30 farmers interviewed, 23.3% of them applied DDT on their farmlands whereas 6.6% of the farmers applied emmamectin. Thus DDT was the mostly applied pesticide on the farmlands by the farmers, while emmamectin was the least applied pesticide ($P < 0.05$, t-test).

For the 30 farmers interviewed, 80% representing 24 of the farmers agreed that they regularly change the types of pesticide they apply on their farmlands, while 10% of the farmers said they sometimes change the types of pesticide they apply, and the remaining 10% indicated they do not change the types of pesticide they apply on their farmlands (Fig. 3). The percentage of farmers who regularly change the type of pesticide they apply on their farmlands or crops statistically differs from the percentage of farmers who sometimes change or do not change the type of pesticides they apply on their farmlands at $P < 0.01$ (t-test).

Thirty percent (30%) of the 30 farmers changed the types of pesticide they applied on their farmlands, and gave the reason that new types of pesticide are more effective. Forty percent (40%) of the farmers indicated ineffectiveness of pesticides as the reason for changing the types of pesticide they applied on their farmlands, whereas ten percent (10%) said they do change the types of pesticide they apply on their farmlands due to recommendations given to them by retailers. The remaining twenty percent (20%) consisting of 6 farmers gave other reasons for changing the types of pesticide they apply on their farms, whereas none of the farmers acted based on recommendations from agricultural officials (Fig. 4). The percentages of the farmers who change the types of pesticides they apply on their farmlands due to more effective and ineffective pesticides, recommendations given to them by retailers, and other reasons differ statistically from the zero percent of farmers who do take recommendations from agricultural officials at $p < 0.05$ (t-test).

The percentage germination at seedlots with no pesticides applied increases with time, and differs statistically from the percentage germination at seedlots with pesticides applied at $p < 0.05$ and 0.01, respectively (t-test).

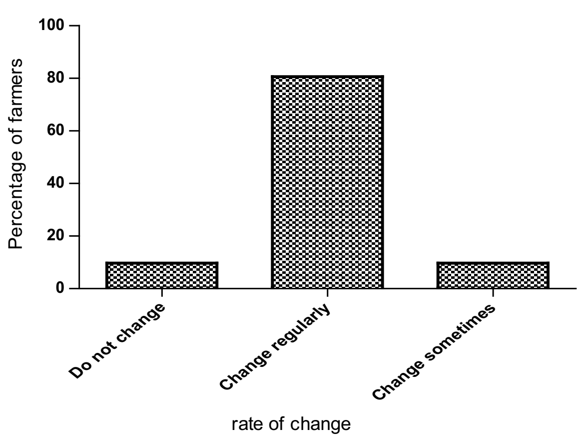

Fig. 3 Pesticide use pattern by the farmers at Tono Irrigation Dam Area, Navrongo

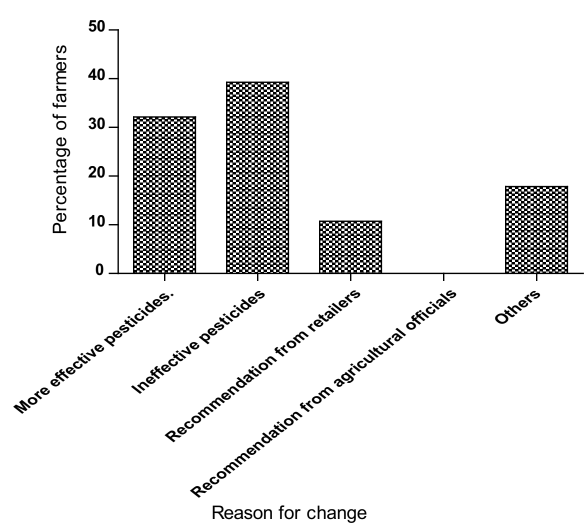

Fig. 4 Reasons for change of pesticides by farmers at Tono Irrigation Dam Area, Navrongo

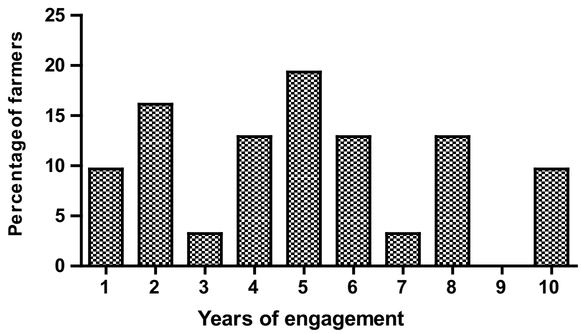

Fig. 5 Years of engagement in vegetable cultivation by farmers at Tono Irrigation Dam Area, Navrongo, Ghana

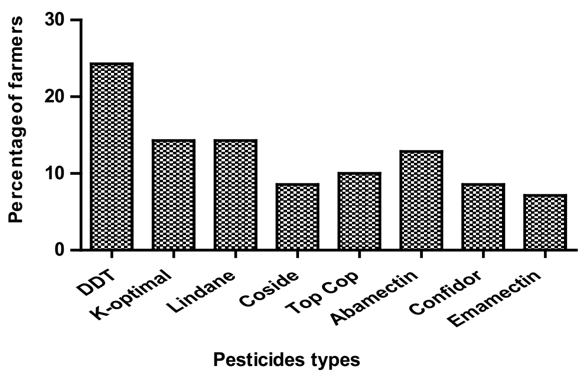

Fig. 6 Pesticide types applied on farmlands by farmers (%) at Tono Irrigation Dam Area, Navrongo

The seedling vigor index at seedlots with no pesticides applied differs statistically from the seedling vigor index at seedlots with pesticides applied at $p < 0.05$ (t-test).

The percentage germination at seedlots with no pesticides applied increases with time, and differs statistically from the percentage germination at seedlots with pesticides applied at $p < 0.05$ and 0.01, respectively (t-test).

The seedling vigor index at seedlots with no pesticides applied differs statistically from the seedling vigor index at seedlots with pesticides applied at $p < 0.05$ (t-test).

Discussion

The years of farmers' engagement in vegetable cultivation in the survey ranged from 1 to 10. Of all the farmers engaged in farming within the ten (10) year's period, 19% have been into vegetable cultivation for five (5) years, the highest percentage of farmers who have been into vegetable cultivation for the said period. The duration with the least percentage of farmers was nine (9) years, represented by 0% of the farmers interviewed (Fig. 5). The years of engagement in vegetable cultivation by the farmers interviewed, and the types of pesticides they applied on their farmlands, mostly non-degradable pesticides are possible indicators of pesticide residue accumulation in the vegetables cultivated at the Tono Irrigation Dam Area (Figs. 5 and 6). As a result of factors such as the availability of a ready market, ease of storage and preservation, pepper was cultivated by most of the farmers followed by okra and garden egg in that order, with tomato being the least cultivated vegetable due to its short shelf life coupled with lack of a storage facility (Fig. 2, $p < 0.05$). According to Fianko and his co-workers, the application of pesticides to safeguard crops against pests has greatly decreased losses and increased crop yields, including cereals, fruits, vegetables, and other crops, ever since their invention (Fianko et al. 2011). Owing to this, dangerous chemicals are being employed by some Ghanaian farmers to control pests in their farms. Thus, the revelation by the present field survey which highlights the use of eight different pesticides by farmers at the Tono Irrigation Dam area is not a surprise (Fig. 6). As a result of pest attacks, vegetables are produced under high pesticide pressure. Some of the pesticides were appropriate for use on the vegetables being investigated while others have been banned for use in Ghana. Confidor® and kocide®, which are approved for pest control in *Theobroma cacao* L. (cocoa) production were found to be used in vegetable cultivation at the Tono Irrigation Dam area. However, these two pesticides were the least used pesticides. Dichlorodiphenyl trichloroethane which has been completely banned for any use, and lindane were the most extensively used pesticides (Fig. 6). Despite the restriction by Ghana Ministry of Food and Agriculture (MoFA) (Fianko et al. 2011) on the use of lindane on cocoa only, it was used on the vegetables cultivated at Tono Irrigation Dam Area. The low cost, effectiveness and broad-spectrum activity of these pesticides could have prompted their use (Fianko et al. 2011). The survey also revealed that the farmers altered the use of pesticides regularly (Fig. 3). The reason for changing of pesticides by farmers ranged from efficacy issues to recommendation by retailers and producers (Fig. 4). It was a common practice for farmers to mix different pesticides without considering their active ingredients and compatibility. These practices may well lead to unsafe compounds reaching human nourishment with resultant hostile effects on human well-being. This pesticide abuse as indicated by the farmers resulted from inadequate knowledge as all the farmers interviewed complained of lack of access to agricultural extension agents. Farmers mostly depended on their colleague farmers and agrochemical dealers to select pesticides for their crops. The knowledge from such sources may not be better than that of the receiving farmer.

Pesticides are known to leave residues on vegetables when sprayed on them as reported by Ssemugabo et al. (2022). The present work confirmed the presence of

Table 1 Pesticide residues in pepper cultivated at Tono Irrigation Dam Area, Navrongo

Pesticides detected	Concentration (μg/Kg) MEAN ± SEM	EU-MRL (μg/Kg)
O'P-DDT	0.17* ± 0.0173877	0.05
P'P DDT	0.07* ± 0.0087369	0.05
O'P-DDD	0.33* ± 0.0431432	0.05
P'P DDE	0.076* ± 0.0132791	0.05
α-HCH	0.18* ± 0.018	0.01
β-HCH	0.62* ± 0.049689	0.01
δ-HCH	0.35* ± 0.025697	0.01
Lindane	0.06* ± 0.0103923	0.01
Dieldrin	0.04* ± 0.0075056	0.01
Endrin	< 0.01	0.01
Aldrin	< 0.01	0.01

Total pesticide residues analysis performed are matched with the European Union (EU) guideline values for vegetables

HCH, Hexachlorocyclohexane; DDT, Dichlorodiphenyltrichloroethane; DDE, Dichlorodiphenylethylene; DDD, Dichlorodiphenyldichloroethane

* Values designated by asterisks represent pesticide residue concentrations that are higher than the European Union—Minimum Residue Limits (EU-MRLs) for the respective pesticides

Table 2 Pesticide residues in garden egg cultivated at Tono Irrigation Dam Area, Navrongo

Pesticides detected	Concentration (μg/Kg) MEAN ± SEM	EU-MRL (μg/Kg)
O'P-DDE	0.056* ± 0.09815	0.05
P'P DDD	0.06* ± 0.070238	0.05
O'P-DDT	0.62* ± 0.970773	0.05
P'P DDT	0.443* ± 0.38223	0.05
O'P-DDD	1.00* ± 0.301717	0.05
P'P DDE	0.04 ± 0.069282	0.05
α-HCH	0.283 ± 0.319739	0.01
β-HCH	0.05 ± 0.068069	0.01
Lindane	0.29* ± 0.387427	0.01
δ-HCH	0.35* ± 0.06245	0.01
Heptachlor + heptachlor epoxide	0.27* ± 0.467654	0.27*
Lambda cyahalothrin	0.29 ± 0.347898	0.5
Dieldrin	0.26* ± 0.441701	0.01
Endrin	0.059* ± 0.020817	0.01
Aldrin	0.10* ± 0.178979	0.01

Total pesticide residues analysis performed are matched with the European Union (EU) guideline values for vegetables

HCH, Hexachlorocyclohexane; DDT, Dichlorodiphenyltrichloroethane; DDE, Dichlorodiphenylethylene; DDD, Dichlorodiphenyldichloroethane

* Values designated by asterisks represent pesticide residue concentrations that are higher than the EU-MRLs for the respective pesticides

pesticide residues in the pepper, garden egg and okra cultivated at the Tono Irrigation Dam Area, Navrongo (Tables 1, 2 and 3). The residues are harmful to human health when they exceed their calculated maximum residue levels (mrl) (Ivanova et al. 2016). Pepper, garden egg and okra are consumed without removal of their outer peels which could contribute to high risk of pesticide action on humans. The main pesticide residues detected in the pepper, garden egg and okra samples are dichlorodiphenyltrichloroethane, its metabolites (Dichlorodiphenyldichloroethane and dichlorodiphenylethylene) and lambdacyahalothrin. Other pesticide residues detected in the samples are heptachlor and its epoxide, aldrin, endrin and dieldrin (Tables 1, 2 and 3). Ortho, para-dichlorodiphenyltrichloroethane and para, para-dichlorodiphenyltrichloroethane were detected in the pepper, okra and garden egg. Concentrations of ortho, para-dichlorodiphenyltrichloroethane in pepper and garden egg were 0.17 μg/Kg and 0.62 μg/Kg respectively, above their mrl of 0.05 μg/Kg (Tables 1 and 2). In a report from the United States Agency for Toxic Substances and Disease Registry (Agency for Toxic Substances and Disease Registry 2017), DDT may be dechlorinated to dichlorodiphenyldichloroethane (DDD) by anaerobic processes or slowly converted to dichlorodiphenylethylene (DDE) aerobically. Dichlorodiphenyldichloroethane and dichlorodiphenylethylene are known as metabolites of DDT (Mermer et al. 2020). The metabolites of dichlorodiphenyltrichloroethane detected in the pepper, garden egg and okra samples included ortho, para-dichlorodiphenyldichloroethane, para, para-dichlorodiphenyldichloroethane, ortho, para- dichlorodiphenylethylene and para, para-dichlorodiphenylethylene (Tables 1, 2 and 3). In the pepper sample, only ortho, para -dichlorodiphenyldichloroethane and para, para-dichlorodiphenylethylene were detected at concentrations above their instructed maximum residue limits (Table 1). In the garden egg sample, all metabolites (o,p-DDD, p,p-DDD, p,p-DDT, o,p-DDE and p,p-DDE) were detected with para, para-dichlorodiphenylethylene and para, para-dichlorodiphenyltrichloroethane below the instructed maximum residue limit of 0.05 μg/Kg (Table 2). Para, para'-dichlorodiphenyldichloroethane and ortho, para- dichlorodiphenyldichloroethane detected in the okra samples were all below their instructed maximum residue levels (Table 3). Even though dichlorodiphenyltrichloroethane has been banned in Ghana due to its toxicity and non-degradable nature (Fianko et al. 2011), its high concentrations detected in the pepper and garden egg samples indicated considerable use of the pesticide in the study area. Moreover, due to its low vapor pressure, low water solubility and high particle affinity, dichlorodiphenyltrichloroethane is less transportable via air and water and hence found in high concentrations in areas close to point sources (Chattopadhyay and Chattopadhyay

Table 3 Pesticide residues in okro cultivated at Tono Irrigation Dam Area, Navrongo

Pesticides detected	Concentration (μg/Kg) MEAN ± SEM	EU-MRL (μg/Kg)
Lindane	0.06* ± 0.109697	0.01
Heptachlor + Heptachlor epoxide	0.30* ± 0.310215	0.01
Aldrin	0.137* ± 0.236714	0.01
Lambda cyahalothrin	0.19 ± 0.257164	0.5
O'P-DDD	0.03 ± 0.02	0.05
Endrin	< 0.01	0.01
P'P DDD	< 0.01	0.05
O'P-DDT	0.03 ± 0.005774	0.05
α –HCH	< 0.01	0.05*
β-HCH	0.13* ± 0.146401	0.01

HCH, Hexachlorocyclohexane; DDD, Dichlorodiphenyldichloroethane; DDT, Dichlorodiphenyltrichloroethane; DDE, Dichlorodiphenylethylene

* Values designated by asterisks represent pesticide residue concentrations that are higher than the EU-MRLs for the respective pesticides

2015). Thus, its high concentrations in the vegetable samples. Another pesticide residue detected in the pepper, garden egg and okra were lindane (gamma hexachlorocyclohexane) with concentrations of 0.06 μg/Kg, 0.269 μg/Kg and 0.06 μg/Kg respectively. This residue was all above the set maximum residue limits in all three vegetables (Tables 1, 2 and 3).

In the breakdown of lindane (gamma hexachlorocyclohexane), its isomers, alpha hexachlorocyclohexane, beta hexachlorocyclohexane and delta hexachlorocyclohexane, which were detected in the pepper, garden egg and okra samples are produced as by products and hence are included in its residues. Alpha hexachlorocyclohexane, beta hexachlorocyclohexane and delta hexachlorocyclohexane were all detected in the pepper sample at concentrations higher than their permitted maximum residue limits (Table 1). All three metabolites were also detected in garden eggs still at concentrations above their permitted mrl (Table 2). Only alpha hexacyclochlorohexane and beta hexachlorocyclohexane were detected in okra at concentrations below and above mrl, respectively (Table 3). Thus, only beta hexachlorocyclohexane exceeded its permitted maximum residue level, and indicated okra toxicity to humans.

Even though alpha, beta and gamma hexachlorocyclohexane are isomers of lindane, they lack the insecticidal properties of lindane. In terms of toxicity, they are relatively more toxic than lindane and their presence in the environment and vegetables is an issue of great concern (O'reilly and Yarto 2013).

According to results of the field survey, lamdacyahalothrin was one of the most widely used pesticides (Fig. 2). Its residues were detected in garden eggs and okra at concentrations below their maximum residue levels of 0.29 and 0.19 μg/Kg, respectively (Tables 2 and 3). Lambdacyahalothrin belongs to the class of pyrethoids which are relatively less toxic and degrade at a much faster rate than organochlorines such as DDT and lindane. It acts on the central nervous system causing changes in the dynamics of Na^+ channels in the membrane of nerve cell, causing it to increase its opening time prolonging sodium current across the membrane in both insects and vertebrates. This event leads to neuronal hyper-excitation which causes paralysis and death.

Pesticides such as heptachlor and heptachlor epoxide, aldrin, endrin and aldrin, captured in the survey were detected in the pepper, garden egg and okra samples (Tables 1, 2 and 3). Owing to the continuous use of these pesticides, they are persistent in the environment and can result in residue problems in subsequently cultivated crops. Since most of the farmers at the Tono Irrigation Dam Area have been engaged in vegetable cultivation for a number of years (Fig. 5), the presence of these pesticide residues in the pepper, garden egg and okra could be attributed to application in previous years. Some researchers also suggest that some pesticide companies mix them during production of unbanned pesticides in order to achieve the desired results.

Similar research works in the literature, indicated the presence of pesticide residues in fishes, vegetables, water sediments, mother's milk and blood samples (Ssemugabo et al. 2022; Chattopadhyay and Chattopadhyay 2015). Since these chemicals are toxic to living organisms, increased accumulation in the food chain may pose serious health hazards to the general populace.

The effects of DDT and lambdacyahaloyhrin on growth of pepper, garden egg and okra were expressed by indices of seed germination and seedling vigor. The percentage germination for the pepper, garden egg and okra seed lots increased as time (days) increased, and decreased

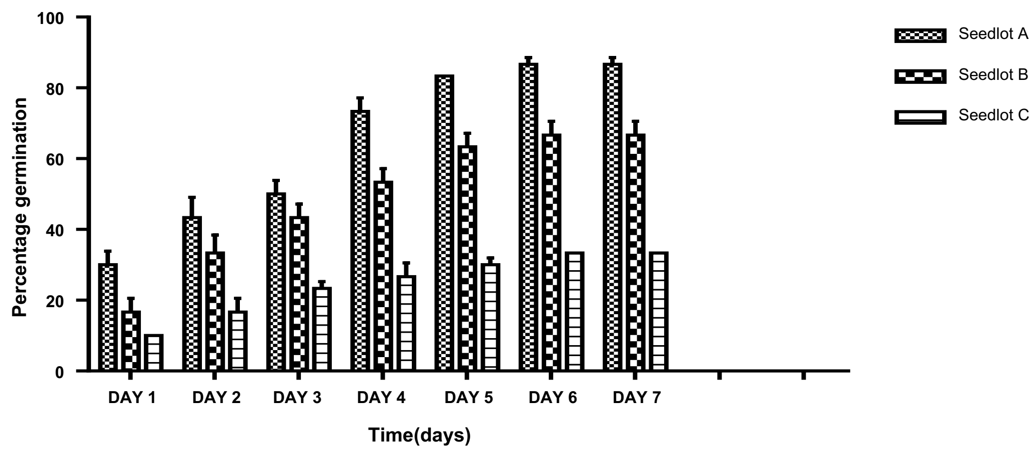

Fig. 7 Percentage germination of pepper seeds with time

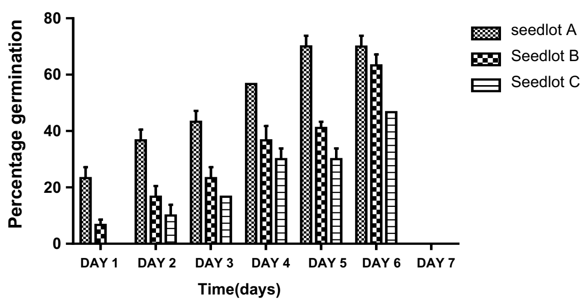

Fig. 8 Percentage germination of garden egg seeds against time

as concentrations of pesticide mixtures were increased (Figs. 7, 8 and 9). Seed lot A of the pepper to which no pesticide was applied had 83% germination, seed lot B to which DDT (15 ml/15 L of water) and lambdacyahalothrin (10 ml/15 L of water) were applied had 67%, and seed lot C to which DDT (30 ml/15 L of water) and lambdacyahalothrin (20 ml/15 L of water) were applied had the least percentage germination of 43%. The higher the concentration of the pesticide mixture, the lower the percentage germination of the seeds, and the lower the vigor of the seedlings (Table 4, Fig. 10). Similar results were obtained for garden egg and okra seeds and seedlings (Tables 5 and 6, Figs. 11 and 12). Thus, the percentage germination and vigor of the pepper, garden egg and okra seeds and seedlings were inhibited for seed lots treated with the pesticide mixture when compared to the seed lot not treated with any pesticides.

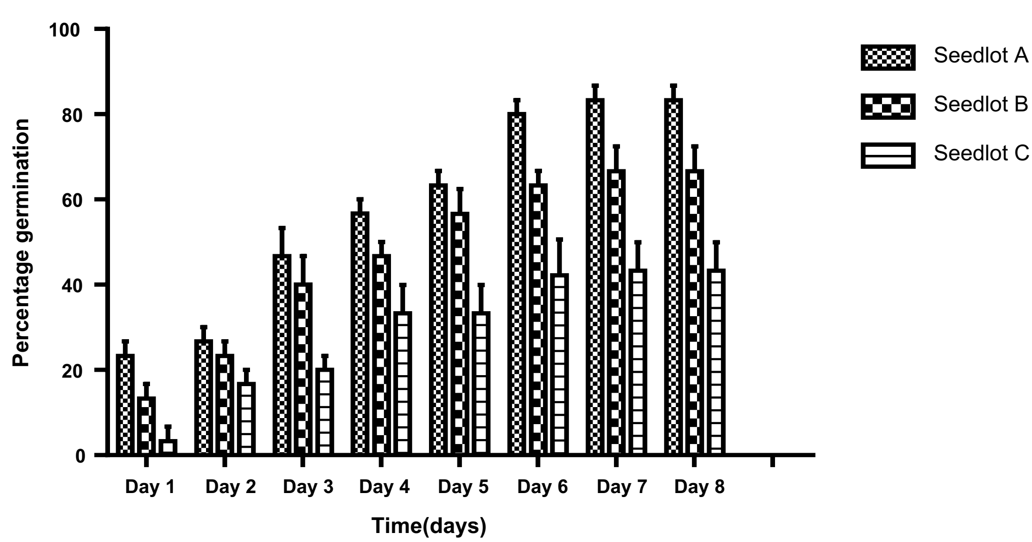

Fig. 9 Percentage germination of okra against time

Table 4 Effects of pesticides on germination and vigor of pepper seed and seedling

Seedlots	Root length (cm) Mean ± SEM	Shoot length (cm) Mean ± SEM	% Germination Mean ± SEM	Seedling vigour index Mean ± SEM
A	5.5 ± 0.26	7.5 ± 0.26	83.33 ± 3.34	10.82 ± 0.30
B	5.13 ± 0.21	7.03 ± 0.21	66.66 ± 5.77	8.12 ± 0.78
C	4.73 ± 0.21	6.8 ± 0.1	43.33 ± 6.67	4.98 ± 0.66

A, No Pesticides applied; B, DDT (15 ml/15 L of water) and lambdacyahalothrin (10 ml/15 L of water) applied; C, DDT (30 ml/15 L of water) and lambdacyahalothrin (20 ml/15 L of water) applied

The percentage germination at seedlots with no pesticides applied differs statistically from the percentage germination at seedlots with pesticides applied at $p < 0.05$ and 0.01, respectively (t-test)

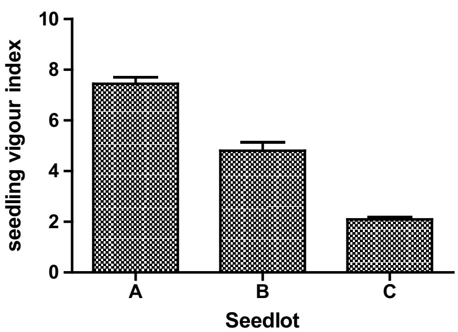

Fig. 10 Seedling vigour of pepper seeds for various seedlots

The fore-mentioned observation could be attributed to increasing pesticide concentrations in the soil which affects microbial activity, reducing soil fertility. Detoxification capacity of the soil also largely depends on its microbial activity. The higher the microbial activity, the greater the capacity of the soil to counteract the effect of a pesticide. Often pesticide residues in the soil vary depending on concentrations of pesticides applied as well as their nature. As a result of the high organic carbon partition coefficient of dichlorodiphenyltrichloroethane, it is strongly adsorbed to the soil. Also, in soils with high boron, potassium and iron contents, dichlorodiphenyltrichloroethane is degraded at a faster rate (Mermer

Table 5 Effects of pesticides on germination and vigor of garden egg seed and seedling

Seedlots	Root length (cm)	Shoot length (cm)	% Germination	Seedling vigour index
A	2.47 ± 0.06	3.9 ± 0.1	69.99 ± 6.68	4.46 ± 0.48
B	1.6 ± 0.01	2.17 ± 0.12	63.32 ± 6.67	2.38 ± 0.24
C	1.27 ± 0.06	1.3 ± 0.2	46.67 ± 8.7	1.19 ± 0.1

The percentage germination at seedlots with no pesticides applied differs statistically from the percentage germination at seedlots with pesticides applied at $p < 0.05$ (t-test)

The percentage germination at seedlots with no pesticides applied increases with time, and differs statistically from the percentage germination at seedlots with pesticides applied at $p < 0.05$ and 0.01, respectively (t-test)

The seedling vigor index at seedlots with no pesticides applied differs statistically from the seedling vigor index at seedlots with pesticides applied at $p < 0.05$ (t-test)

A, No Pesticides applied; B, DDT (15 ml/15 L of water) and Lambdacyahalothrin (10 ml/15 L of water) applied; C, DDT (30 ml/15 L of water) and Lambdacyahalothrin (20 ml/15 L of water) applied ± SEM

Table 6 Effects of pesticides on germination and vigor of okra seed and seedling

Seedlots	Root length	Shoot length	Percentage Germination	Seedlind vigour index
A	3.2 ± 0.2	5.4 ± 0.4	86.66667 ± 3.34	7.446653 ± 0.45
B	2.6 ± 0.17	4.6 ± 0.17	66.66667 ± 6.67	4.806667 ± 0.58
C	2.1 ± 0.2	4.2 ± 0.26	33.33	2.09979 ± 0.15

A, No Pesticides applied; B, DDT (15 ml/15 L of water) and Lambdacyahalothrin (10 ml/15 L of water) applied; C, DDT (30 ml/15 L of water) and Lambdacyahalothrin (20 ml/15 L of water) applied ± SEM

The percentage germination at seedlots with no pesticides applied differs statistically from the percentage germination at seedlots with pesticides applied at $p < 0.05$ and 0.01, respectively (t-test)

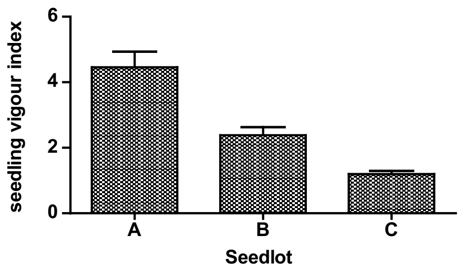

Fig. 11 Seedling vigour index of garden egg seedlings against seed lots

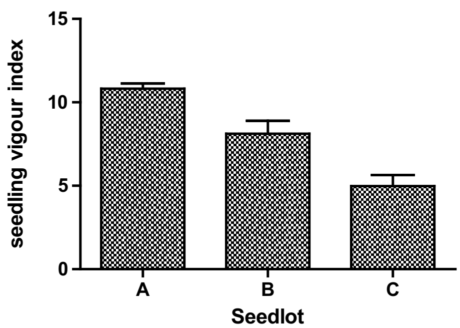

Fig. 12 Seedling vigor index of okra seedlings against seed lots

et al. 2020). This suggests involvement of these metals in microbial degradation of dichlorodiphenyltrichloroethane. On a contrary, boron is required by plants for protein formation, nitrogen metabolism, cell division and cell wall formation. Thus the important metabolic activities of plants are disturbed when there is boron deficiency. Also, the boron ion aids movement of potassium ions into plants. Thus, the presence of dichlorodiphenyltrichloroethane in soil may inhibit the uptake of essential nutrients from the soil by plants, affecting the growth of plants negatively. We recommend further research be conducted to assess the potential health implications associated with the cultivation and consumption of vegetables in Navrongo, Ghana.

Conclusion

The pepper, garden egg and okra grown on farmlands at the Tono Irrigation Dam Area contain dichlorodiphenyltrichloroethane, lindane, dieldrin, endrin, heptachlor + heptachlor cyahalothrin, heptachlor + heptachlor epoxide and hexachlorocyclohexane residues above the acceptable maximum residue limits of the European Commission and hence pose a potential threat to the health of vegetable consumers. These vegetables are unsafe for human consumption. The banned heptachlor and aldrin detected in the vegetables indicate long-lasting environmental contamination Also, the dichlorodiphenyltrichloroethane and lambdacyahalothrin mixture applied on seed lots inhibited germination and vigor of pepper, garden egg and okra seeds and seedlings, and demonstrated retarded growth of pepper, garden egg and okra plants cultivated at the Tono Irrigation Dam Area. The farmers growing pepper, garden egg and okra on farmlands at the Tono Irrigation Dam Area, Navrongo are advised to discontinue the use of prohibited and harmful pesticides. Sensitization of these farmers by Non-Governmental Organizations and Ministry of Food and Agriculture, Ghana on approved pesticides for vegetable cultivation and methods of usage to ensure safety is recommended. Future research to assess the potential health implications associated with the cultivation and consumption of vegetables in Navrongo is recommended.

Acknowledgements
The authors are thankful to the authorities of Ghana Atomic Energy Commission, Accra-Ghana for permitting the use of their laboratories to conduct this research.

Author contributions
VCM conceived the study and supervised the work. VCM, ODY and UFI were involved in all stages of the investigations, development of protocols, data acquisition and analysis, writing, corrections, proofreading and final editing of the manuscript.

Funding
No specific funding was received for this study. It was supported by the authors.

Availability of data and materials
The data upon which the conclusions in this work are made is included in the article.

Declarations

Competing interests
The authors declare that they have no competing interests concerning this work.

Author details
[1] Department of Applied Chemistry, C.K. Tendam University of Technology and Applied Siences, P. O. Box 24, Navrongo, Ghana.

Received: 18 August 2023 Accepted: 12 May 2024
Published online: 08 June 2024

References

Adams S, Issaka RN, Quansah GW, Amfo-otu R, Bagna S. Assessment of irrigation water quality of Tono dam in Navrongo, Ghana. J Biodivers Environ Sci. 2014;4(3):187–95.

Agency for Toxic Substances and Disease Registry, United States. Chapter 5. Potential for human exposure. Toxicol profiile DDT, DDE DDD. Atlanta: ATSDR; 2017.

Aniah P, Kaunza-Nu-Dem MK, Dong-Uuro PP, Ayembilla JA, Osumanu IK. Vegetable farmers' knowledge on pesticides use in Northwest Ghana. Environ Dev Sustain. 2021;23(5):7273–88. https://doi.org/10.1007/s10668-020-00916-6.

Chattopadhyay S, Chattopadhyay D. Remediation of DDT and its metabolites in contaminated sediment. Curr Pollut Rep. 2015;1(4):248–64.

Donkor A, Osei-Fosu P, Dubey B, Kingsford-Adaboh R, Ziwu C, Asante I. Pesticide residues in fruits and vegetables in Ghana: a review.

Environ Sci Pollut Res. 2016;23(19):18966–87. https://doi.org/10.1007/s11356-016-7317-6.
Fianko JR, Donkor A, Lowor ST, Yeboah PO. Agrochemicals and the Ghanaian environment, a review. J Environ Prot (Irvine, Calif). 2011;02(03):221–30. https://doi.org/10.4236/jep.2011.23026.
1. O. Lalah J, O. Otieno P, Odira Z, A. Ogunah J. Pesticides: Chemistry, manufacturing, regulation, usage and impacts on population in Kenya. In: Pesticides - Updates on Toxicity, Efficacy and Risk Assessment. IntechOpen; 2022. Vol. i (Issue tourism, p. 13). IntechOpen. https://doi.org/10.5772/intechopen.105826
Mermer S, Yalcin M, Turgut C. The uptake modeling of DDT and its degradation products (o, p´-DDE and p, p´-DDE) from soil. SN Appl Sci. 2020;2(4):1–7. https://doi.org/10.1007/s42452-020-2577-7.
O'reilly J, Yarto M. North American regional action plan on lindane and other hexachlorocyclohexane isomers prepared for the CEC. Montreal: Commission for Environmental Cooperation; 2013.
Onwona Kwakye M, Mengistie B, Ofosu-Anim J, Nuer ATK, Van den Brink PJ. Pesticide registration, distribution and use practices in Ghana. Environ Dev Sustain. 2019;21(6):2667–91. https://doi.org/10.1007/s10668-018-0154-7.
ŠERÁ B. Methodological contribution on seed germination and seedling initial growth tests in wild plants. Not Bot Horti Agrobot Cluj-Napoca [Internet]. 2023 Jun 20;51(2):13164. Available from: https://www.notulaebotanicae.ro/index.php/nbha/article/view/13164
Sharma S, Kumar S, Kumar V, Sharma R. Pesticides and vegetables: ecological and metabolic fate with their field and food significance. Int J Environ Sci Technol. 2023;20(2):2267–92. https://doi.org/10.1007/s13762-021-03716-1.
Ssemugabo C, Guwatudde D, Ssempebwa JC, Bradman A. Pesticide residue trends in fruits and vegetables from farm to fork in Kampala Metropolitan Area, Uganda—a mixed methods study. Int J Environ Res Public Health. 2022;19(3):1350.
Tudi M, Daniel Ruan H, Wang L, Lyu J, Sadler R, Connell D, et al. Agriculture development, pesticide application and its impact on the environment. Int J Environ Res Public Health. 2021;18(3):1112.

Publisher's Note