Introduction

Vegetables are an important part of the human diet due to their high nutritional value and as important sources of vitamins (C, A, B6, thiamine, niacin, E), minerals, and dietary fiber. Production of vegetables in Sudan is rapidly increasing to meet the needs of the growing population. A wide range of vegetables and fruits are grown in Sudan due to the high availability of arable land, supply of irrigation water and suitable climatic conditions. According to the Food and Agriculture Organization of the United Nations (FAO), vegetable production in Sudan has increased annually in cultivated area and quantity.

Background. Eggplant is a popular food item in Sudan, however pesticides are heavily used.

Objective. To investigate the presence of pesticide residues in fresh eggplants in Khartoum State, Sudan.

Methods. Eggplant fruit samples from three different regions in Khartoum State (central vegetable market, east Nile farms, and west Nile farms) were analyzed for residues of commonly used pesticides. Pesticide residues were analyzed by gas chromatography coupled with mass spectrometry and results were expressed in µg/kg fruit.

Results. Out of the 11 active ingredients analyzed, residues were identified for four pesticides (imidacloprid, dimethoate, endosulfan (α and β isomers) and 2, 4-D). Levels of omethoate, diazinon, malathion, chlorpyrifos, atrazine, and pendimethalin were below the detection limits.

Conclusions. Residues of four insecticides out of the 11 analyzed (imidacloprid, dimethoate, endosulfan (α, β isomers), and 2, 4-D) were detected in the current study. The health implications of these violative levels should be regularly observed along with strict enforcement of laws and regulations coupled with agricultural extension interventions.

Competing Interests. The authors declare no competing financial interests.

Keywords. eggplant, pesticide residues, Sudan.

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Pesticide Residues in Eggplant Fruit from Khartoum State, Sudan

Methods

Eggplant fruit samples (2-3 kg per sample) were collected randomly from three different areas in Khartoum State, Sudan: two central vegetable market locations (15.6726 N, 32.5376 E, 15.5304 N, 32.5576 E) and three east Nile farms (15.5133 N, 32.6534 E) and three west Nile farms (15.2578 N, 32.5015 E) (Figure 1). Twenty-seven (27) samples were collected in total, nine from each of the three study areas. The FAO Codex method was followed in sample collection at all locations. The collected samples were placed in paper bags, labeled and transferred immediately for extraction to the pesticide analytical laboratory, Faculty of Agriculture, University of Khartoum.

Chemicals and reagents

Ethyl acetate (purity 99.8%), acetone (purity 99.98%), anhydrous sodium sulphate (purity 99.5%), and dichloromethane (purity 99.98%) were purchased from El Waldain Company, Khartoum Arabic market. Analytical standards (99% purity) of endosulfan (α and β), dimethoate, diazinon, malathion, atrazine, chlorpyrifos, pendimethalin, oxamethoate, and imidacloprid were obtained from the Plant Protection Directorate (Ministry of Agriculture, Khartoum North, Sudan).

Extraction and partitioning

The collected samples (unpeeled eggplant fruits) were sliced into small pieces, mixed thoroughly and about 50 g of each were weighed using a sensitive balance and blended with 10 g of anhydrous sodium sulphate at high speed (22000 rpm) for two minutes using a chemical resistant blender (National Analytical Corporation, Mumbai, India). The sample was then extracted with 100 ml
acetone on a mechanical shaker for 1 hour using the method of Kumari et al. The extract was then filtered on Whatman filter No. 1, concentrated to 40 ml by rotary evaporator and subject to liquid-liquid extraction with ethyl acetate (50, 30, 20 ml) after dilutions with 100 ml 10% aqueous sodium chloride solution. The organic phase was collected in an Erlenmeyer flask and concentrated to 10 ml by rotary evaporator.

Clean-up

Clean-up was carried out using a solid phase extraction column using ready-packed columns with silica gel and activated charcoal (5:1 wt/wt) topped with anhydrous sodium sulphate. The columns were pre-washed with 50 ml of acetone and hexane, respectively. Finally, the extract was passed through the columns and eluted with a 125 ml mixture of acetone:hexane (3:7 vol/vol). The cleaned extract was dried by rotary evaporator at 40°C until complete dryness and then reconstituted in 10 ml hexane and stored 4°C for analysis by gas chromatography coupled with mass spectrometry.

Chromatographic analysis

The pesticide residue analysis was determined using gas chromatography coupled with mass spectrometry. Samples were analyzed using a Shimadzu GC-MSQP 2010 (Tokyo, Japan) with an AOC-5000 auto sampler. The gas chromatograph was fitted with an Rt5-MS capillary column 30 m x 0.25 mm internal diameter x 0.25 μm film thicknesses from Restek (UK). Helium (purity ≥ 99.999%) was used as a carrier gas at a flow rate of 1.69 ml/min. The splitless injection temperature was 230°C. The oven temperature was programmed from initial temperature of 50°C for 3 minutes, raised at 10°C per minute to 200°C and held for 5 minutes, then increased by 3°C per minute to 230°C and held for 2 minutes. The mass spectrometer was operated with an electron impact source in scan mode. The electron energy was 70 eV, and the interface temperature was maintained at 200°C. The solvent delay was set to 10 minutes. The retention time of standard pesticides are shown in Figures 2, 3 and 4. Detection limits are given in Table 1. The recovery of the method ranged from 70-120%. No pesticide residues were detected in the calibration blanks.

The pesticide residues present in the eggplant samples were identified by matching their retention times and mass-spectrum to those of analytical

| Pesticides    | CAS number | Minimum detectable level (μg/kg) | Retention time (minutes) |
|---------------|------------|---------------------------------|--------------------------|
| 2,4-D         | 94-75-7    | 30                              | 17.029                   |
| Omethoate     | 1113-02-6  | 50                              | 17.137                   |
| Dimethoate    | 60-51-5    | 30                              | 18.904                   |
| Atrazine      | 1912-24-9  | 10                              | 19.153                   |
| Diazinon      | 333-41-5   | 50                              | 19.739                   |
| Imidacloprid  | 138261-41-3| 50                              | 22.514                   |
| Malathion     | 121-75-5   | 50                              | 23.089                   |
| Chlorpyrifos  | 2921-88-2  | 50                              | 23.622                   |
| Pendimethalin | 40487-42-1 | 10                              | 25.297                   |
| Endosulfan α  | 115-29-7   | 10                              | 27.230                   |
| Endosulfan β  | 115-29-7   | 10                              | 30.450                   |

Abbreviation: CAS number, Chemical Abstract Service Registry Number.

Table 1 — Minimum Detectable Levels and Retention Times of Studied Pesticides
Figure 2 — Chromatogram of omethoate, dimethoate, endosulfan alpha and endosulfan beta

Figure 3 — Chromatogram of imidacloprid

Figure 4 — Chromatogram of 2, 4-D, atrazine, diazinon, malathion, chlorpyrifos and pendimethalin
Table 2 — Levels of Insecticides Residues (µg/kg⁻¹) Detected in Eggplant Samples Collected from Central Vegetable Market and Vegetable Farms in Khartoum State

| Insecticides    | Levels                  | Central vegetable market | East Nile farms | West Nile farms |
|-----------------|-------------------------|--------------------------|-----------------|-----------------|
|                 | Average                 | ND                       | 1040            | ND              |
|                 | Range                   | ND                       | ND-3050         | ND              |
| α-Endosulfan    | Median                  | ND                       | 50              | ND              |
|                 | No. of sample tested + ve(%) | ND                     | 66              | ND              |
|                 | SE±                     | ND                       | 101             | ND              |
|                 | Violative (%) sample*  | ND                       | 33              | ND              |
|                 | Average                 | 50                      | 418             | 70              |
|                 | Range                   | ND-140                   | 164-1090        | ND-120          |
| Total endosulfan| Median                  | -                        | -               | 366             |
|                 | No. of sample tested + ve(%) | 33                    | 100             | 66              |
|                 | SE±                     | 465                      | 108             | 365             |
|                 | Violative (%) sample*  | ND                       | ND              | ND              |
|                 | Average                 | 50                      | 1458            | 70              |
|                 | Range                   | ND-1280                  | 51,1-1042       | ND-178.2        |
| β-Endosulfan    | Median                  | 200                      | 76.4            | 104.3           |
|                 | No. of sample tested + ve(%) | 33                    | 100             | 66              |
|                 | SE±                     | 170                      | 15.3            | 51.7            |
|                 | Violative (%) sample*  | ND                       | ND              | ND              |
|                 | Average                 | ND                       | ND              | ND              |
|                 | Range                   | ND                       | ND              | ND              |
| Omeothate       | Median                  | ND                       | ND              | ND              |
|                 | No. of sample tested + ve(%) | ND                    | ND              | ND              |
|                 | SE±                     | ND                       | ND              | ND              |
|                 | Violative (%) sample*  | ND                       | ND              | ND              |
|                 | Average                 | ND                       | ND              | ND              |
|                 | Range                   | ND                       | ND              | ND              |
| Diazinon        | Median                  | ND                       | ND              | ND              |
|                 | No. of sample tested + ve(%) | ND                    | ND              | ND              |
|                 | SE±                     | ND                       | ND              | ND              |
|                 | Violative (%) sample*  | ND                       | ND              | ND              |
|                 | Average                 | ND                       | ND              | ND              |
|                 | Range                   | ND                       | ND              | ND              |
| Malathion       | Median                  | ND                       | ND              | ND              |
|                 | No. of sample tested + ve(%) | ND                    | ND              | ND              |
|                 | SE±                     | ND                       | ND              | ND              |
|                 | Violative (%) sample*  | ND                       | ND              | ND              |
|                 | Average                 | ND                       | ND              | ND              |
|                 | Range                   | ND                       | ND              | ND              |
| Chlorpyrifos    | Median                  | ND                       | ND              | ND              |
|                 | No. of sample tested + ve(%) | ND                    | ND              | ND              |
|                 | SE±                     | ND                       | ND              | ND              |
|                 | Violative (%) sample*  | ND                       | ND              | ND              |
|                 | Average                 | 1650                     | 2640            | 1547           |
|                 | Range                   | ND-4960                  | 200-4760        | ND-2957         |
| Imidacloprid    | Median                  | -                        | 2970            | 1683            |
|                 | No. of sample tested + ve(%) | 33                     | 100             | 66              |
|                 | SE±                     | 1650                     | 1330            | 856             |
|                 | Violative (%) sample*  | 33                       | 66              | 66              |

Insecticides load/kg: 7629.1 µg/kg; Grand range = ND-4957 µg/kg; Total of samples tested = 75; Total of samples tested + ve (%) = 27.
Abbreviations: +ve, positive; SE, standard error.
*Percentage of samples with level exceeding the MRLs cited by FAO and World Health Organization

Note: March 2020
standards. About 1.0 µl of various concentrations of each analytical standard was injected in the gas chromatography and their peak areas were used for the construction of the standard curves. Duplicate samples of 1 µl from each extract were injected and concentration was determined using Equation 1.

Equation 1

\[ \text{Yield (µg/kg)} = \frac{\text{Area of the sample} \times \text{concentration} \times \text{total volume}}{\text{Area of standard} \times \text{sample weight}} \]

Results

The results of residues analysis of samples are summarized in Tables 2 and 3 and Supplemental Material. Residues were detected in 11% of samples in central vegetable market, 33% of samples from east Nile farms and 22% of samples of west Nile farms. Average violative levels (> FAO Codex maximum residue limits (MRLs)) ranged from 11% (endosulfan α) to 55% (imidacloprid). The highest violations were found to be associated with east Nile farms samples, while the lowest were found to be associated with central vegetable market samples. The most frequently detected pesticides were imidacloprid, dimethoate and β endosulfan (in 66% of samples), followed by 2,4-D (in 33% of samples), and α endosulfan (in 22% of samples). The highest detected levels were found to be associated with the insecticide imidacloprid in all samples, with an average of 1650 µg kg⁻¹ in central vegetable market samples, 2640 µg kg⁻¹ in east Nile farms samples, and 1547 µg kg⁻¹ in west Nile farms samples with corresponding ranges of ND-4960 µg kg⁻¹, 200-4760 µg kg⁻¹ and ND-2957 µg kg⁻¹.

Generally, endosulfan α showed the lowest levels, except in east Nile farm samples where its average was 1040 µg kg⁻¹ with a range of ND-3050 µg kg⁻¹. The highest insecticide loads per kilogram fruit were found in the samples collected from east Nile farms (average total 4175.3 µg kg⁻¹), followed by central vegetable market (1742.7 µg kg⁻¹) and west Nile farms (1711.1 µg kg⁻¹). In addition, the highest frequency of detection (+ ve samples %) and the highest frequency of violative levels (violation %) followed the same order (Tables 2 and 3 and Supplemental Material).

The herbicide 2,4-D was the only herbicide detected and only in samples from east Nile and west Nile farms. Its level was relatively higher in east Nile farms (38.7 µg kg⁻¹) versus west Nile farm samples (37.7 µg kg⁻¹). The herbicide 2,4-D levels detected were below FAO Codex MRLs. Atrazine and pendimethalin levels were below the detection limit (Table 4 and Supplemental Material).

In summary, the average residue load of insecticides and herbicides per kg fruit was about 2443.1 µg kg⁻¹ with a load range of ND-3892.7 µg kg⁻¹, while the total frequency of detection of pesticide residues was 66% (Table 5). Out of the total samples, about 55% were violative. Generally, the highest levels were detected in the east Nile farm samples (3837.8 µg kg⁻¹) followed by west Nile farm samples (1748.8 µg kg⁻¹) and central vegetable market samples (1742.7 µg kg⁻¹). In addition, the level of violations and the frequency of detection followed the same order (Table 3, 5 and Supplemental Material).

Discussion

The current study investigated the level of 11 commonly used pesticides in eggplant samples collected from

| Study area          | Pesticides             | Retention time (minutes) |
|---------------------|------------------------|--------------------------|
| East Nile farms     | 2,4-D                  | 17.029                   |
|                     | Dimethoate             | 18.904                   |
|                     | Imidacloprid           | 22.514                   |
|                     | Endosulfan α           | 27.230                   |
|                     | Endosulfan β           | 30.450                   |
| Central vegetable market | Dimethoate             | 18.904                   |
|                     | Imidacloprid           | 22.514                   |
|                     | Endosulfan β           | 30.450                   |
| West Nile farms     | 2,4-D                  | 17.029                   |
|                     | Dimethoate             | 18.904                   |
|                     | Imidacloprid           | 22.514                   |
|                     | Endosulfan β           | 30.450                   |

Table 3 — Pesticides Detected in Eggplant Samples Collected from Three Study Areas in Khartoum State and Vegetable Farms in Khartoum State
vegetable farms and central vegetable market in Khartoum State, Sudan. Detectable levels were associated with only four pesticides (imidacloprid, dimethoate, endosulfan (α, β isomers) and 2,4-D). One (1) or more of these pesticides were found in many samples from all locations. Not all detected pesticides are authorized for use on eggplant in Sudan (A.H. Ahmed, Plant Protection Directorate, personal communication September 2019).

However, out of 11 studied pesticides, only two were insecticides authorized for use on eggplant in the Sudan: omethoate and dimethoate. The rest are either registered for use on other vegetables or not registered for use on crops. These were included in the present study as farmers interviewed in these areas reported their use on crops. This reflects the urgent need for extension services to be available for farmers in these areas. The current results are in line with results obtained by Hammad et al. who found that tomato samples collected from greenhouses in different locations in Khartoum state contained lambda-cyhalothrin and imidacloprid residues. Levels detected in their study were higher than MRLs established by either Codex Alimentarius or the European Union (EU). Contrary to the current result, Ahmed et al. reported that imidacloprid and its metabolite residues were below the detection limit (0.09 µg) in all samples analyzed (dates, soil and intercropped plants (alfalfa, and grasses) even at the highest dose applied (35 ml/palm). Similar to the current results, Daraghmeh et al. found imidacloprid residues in more than half of the analyzed samples in the West Bank, Palestine, although levels detected were lower than those reported in the current study. The highest level of imidacloprid reported in the study was found in eggplant (460 µkg⁻¹), while the lowest level was found in green beans (80 µkg⁻¹). An increase (11–120%) in imidacloprid concentration was observed in samples from 1999 compared to samples from 1998. Daraghmeh et al. attributed this increase to a possible accumulation of imidacloprid residues in the soil and/or to increased use by local farmers.

Dimethoate residues were detected in 33% of samples from central vegetable market, 100% of samples from east Nile farms and 66% of samples from west Nile farms.

| Herbicides | Levels          | Central vegetable market | East Nile farm | West Nile farm |
|------------|-----------------|---------------------------|----------------|----------------|
| Atrazine   | Average         | ND                        | ND             | ND             |
|            | Range           | ND                        | ND             | ND             |
|            | Median          | ND                        | ND             | ND             |
|            | No. of sample tested + ve(%) | ND                       | ND             | ND             |
|            | SE±             | ND                        | ND             | ND             |
|            | Violative (%) sample * | ND                     | ND             | ND             |
|            | Average         | ND                        | ND             | ND             |
|            | Range           | ND                        | ND             | ND             |
|            | Median          | ND                        | ND             | ND             |
|            | No. of sample tested + ve(%) | ND                       | ND             | ND             |
|            | SE±             | ND                        | ND             | ND             |
|            | Violative (%) sample * | ND                     | ND             | ND             |
|            | Average         | 38.7                      | 37.7           | -              |
|            | Range           | 102.8                     | -              | -              |
|            | Median          | 66                        | 33             | 40.4           | 37             |
|            | No. of sample tested + ve(%) | 40.4                     | 37             | -              | -              |
|            | SE±             | ND                        | ND             | ND             |
|            | Violative (%) sample * | ND                     | ND             | ND             |
| Total of herbicides | 38.7          | 37.7                      | -              | -              |

Note: Average load/kg = 38.2 µg/kg; Grand range = ND-133.49 µg/kg; Total number samples tested +ve(%) = 11.
Abbreviations: ND, not detected; No., number; +ve, positive; SE, standard error.
*Percentage of samples with level exceeding the MRLs cited by FAO and World Health Organization.

Table 4 — Levels of Herbicides Residues (µgkg⁻¹) Detected in Eggplant Samples Collected from Central Vegetable Market and Vegetable Farms in Khartoum State
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West Nile farms. Its respective average concentrations (µg kg⁻¹) and ranges (µg kg⁻¹) were 42.7, 77.3 and 94.1; ND-1280, 51.1-1042 and ND-178.2. The current results partially agree with those of Aldawi et al. and Musa et al. who found higher levels of dimethoate residues (exceeding EU MRLs) in cucumber and sweet pepper samples collected from Khartoum State, Sudan.²¹,²² In contrast, lower levels (0.22 µg kg⁻¹) of dimethoate residues were reported in eggplant samples collected from Ghanaian markets.³⁴ The variation across these studies may be explained by differences in location and use patterns in different vegetable crops.

Residues of endosulfan β were detected in 33% of the samples collected from central vegetable market, 100% of the samples collected from East Nile farms and 66% of the samples collected from West Nile farms. The current results partially agree with Aldawi et al. who found residues of endosulfan α in some samples of cucumbers fruit collected from open fields in Khartoum State, Sudan at a frequency of detection ranging from below the detection limit to 33.3%.²¹ Residues of endosulfan β were not detected in the samples analyzed.²¹ On the other hand, Thanki et al. found residues of endosulfan β ranging from 1280-1420 µg kg⁻¹ in row eggplant samples from Gujarat, India.¹³ In contrast, lower levels (<0.01 µg kg⁻¹) of endosulfan residues were reported in eggplant samples collected from Ghanaian markets.³⁴ Variations across these studies may be explained by differences in location and pesticide use patterns in different vegetable crops.

Endosulfan is the only organochlorine pesticide still permitted for agricultural use in Sudan, where it previously constituted at least 50% of the annual spray regime in cotton until 1992.³⁵ Cotton plant shoots, soil and canal water were sampled and analyzed for residues of endosulfan sprayed on cotton during 1982-1983. Detectable residues were found in all three media, one month after spraying. Concentrations of 590 µg kg⁻¹, 2550 µg kg⁻¹ and 2789 µg kg⁻¹ were detected in soil, water and plants, respectively.³⁶ The occurrence of endosulfan in the samples may be explained by a possible recent illegal use on eggplants, as this insecticide is not registered for vegetable use. Farmers in the area claim to use endosulfan for pest control.³⁰ However, endosulfan does not have a long environmental persistence as a parent compound, but instead it forms a persistent metabolite, endosulfan sulfate.²⁷ Previous studies found endosulfan residues in water, soil, blood and food items in the Sudan.¹²-¹⁴,³⁷

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**Table 5 — Summary of Pesticides Residue (µg kg⁻¹) Detected in Eggplant Samples Collected from Central Vegetable Market and Vegetable Farms in Khartoum State**

| Locations (Coordinates) | Pesticide group | Total average | Total range | Violative (%) |
|-------------------------|-----------------|---------------|-------------|---------------|
| Central vegetable market (15.6726 N, 32.5376 E, 15.5304 N, 32.5576 E) | Insecticides | 1742.7 | ND-4960 | 33 |
| | Herbicides | ND | ND | ND |
| | Total | 1742.7 | ND-4960 | 33 |
| East Nile farms (15.5133 N, 32.6534 E) | Insecticides | 3799.1 | ND-4760 | 66 |
| | Herbicides | 38.7 | ND-134 | ND |
| | Total | 3837.8 | ND-4894 | 66 |
| West Nile farms (15.2578 N, 32.5015 E) | Insecticides | 1711.1 | ND-1711.1 | 66 |
| | Herbicides | 37.7 | ND-113 | ND |
| | Total | 1748.8 | ND-1824.1 | 66 |

Note: Average load/kg fruit = 2443.1 µg/kg; Average range of the load/kg fruit = ND-3892.7 µg/kg; Total of violations in sample (%) = 55.
Abbreviation: ND, not detected.
Furthermore, endosulsan was reported as the main causative agent of human poisoning in Sudan, although most of the reported cases were due to consumption of endosulsan-contaminated food.

The herbicide 2,4-D was detected in samples from east Nile and west Nile farms, with a relatively higher level in the east Nile farms. The presence of 2,4-D in the samples may be due to its recent use in the area (although not claimed by the farmers interviewed), or from drift from nearby farms or from contaminated equipment. Fantke et al. reported that 2,4-D and parathion were the most damaging pesticides across the various crops studied.

Levels of omethoate, diazinon, malathion, chlorpyrifos, atrazine and pendimethalin were below the detection limit. The absence of their residues may be explained by the absence or limited use in the area. Previous studies in Sudan indicated the presence of high levels of malathion, fenithrothion, chlorpyrifos, profenofos, dimethoate, heptachlor, diazinon, ethephon, oxyfluorfen, dimethoate and omethoate in fresh vegetables. Variation across studies may be explained by differences in location and use patterns in different vegetable crops.

Violations (greater than FAO-Codex MRLs) ranged from 11% (endosulfan α) to 55% (imidacloprid). The highest violations were associated with east Nile farms, while the lowest were associated with central vegetable market samples. This partially agrees with Musa et al. and Aldawi et al. who reported the highest frequency (100%) of violations (>MRLs) corresponding to dimethoate, endosulfan β, omethoate, dimethoate and heptachlor. The highest levels, detection and violation frequencies were associated with east Nile farms, while the lowest were associated with central vegetable market samples. The results confirm the presence of residues of some of the most commonly used pesticides in the study area at violative levels, indicating the need for a regular residue monitoring program in these crops. The limited knowledge of farmers on the safe use of pesticides and limited training programs available indicate the need for immediate intervention and enforcement of safety limits. As violative levels were found for imidacloprid and endosulfan, immediate review of their use in vegetables in Sudan is needed, along with detailed studies about the potential health effects which may occur from the consumption of contaminated fruits. Furthermore, strict regulations should be enforced to prevent illegal use of endosulfan in vegetables. Provision of extension services and information on the safe use of pesticides to vegetable farmers are needed to mitigate potential risks to human health and the environment.

Limitations of the present study included a lack of detailed information on pesticide use patterns and safety aspects as well as lack of policy enforcement in the study areas. In addition, the effect that processing eggplant fruits has on the level of pesticide residues was not considered. Further studies examining pesticide residues in other commonly consumed vegetables in the Sudan are needed as there is no regular monitoring program for pesticide residues in vegetables in this area and few studies have examined this issue.

Conclusions

Residues of four insecticides out of the 11 analyzed (imidacloprid, dimethoate, endosulfan (α, β isomers), and 2, 4-D) were detected in the current study. Violative levels were found for imidacloprid and endosulfan. The highest levels and frequency of detection and violation were found for imidacloprid. The highest levels and frequency of detection and frequency of violation were associated with east Nile farms, while the lowest were associated with central vegetable market. Levels of omethoate, diazinon, malathion, chlorpyrifos, atrazine, pendimethalin were below detection limits. The health implications of these violative levels should be regularly observed along with strict enforcement of laws and regulations coupled with agricultural extension interventions.

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References

1. Wargovich MJ. Anticancer properties of fruits and vegetables. HortScience [Internet]. 2000 Jul [cited 2020 Jan 22];35(4):573-5. Available from: https://doi.org/10.21273/HORTSCi.35.4.573
2. Slavin JL, Lloyd B. Health benefits of fruits and vegetables. Adv Nutr [Internet]. 2012 Jul 1 [cited 2020 Jan 22];3(4):506-16. Available from: https://doi.org/10.3945/an.112.002154
3. FAOSTAT: crops [Internet]. Rome: The Food and Agriculture Organization of the United Nations. 1961- [updated 2017; cited 2020 Jan 22]. Available from: http://www.fao.org/faostat/en/#data/QC
4. Abdalla AA. Horticultural aspect of crop diversification in the Sudan. Proceedings of the 13th Annual Conference Philosophical Society of the Sudan; 1965 Dec 3-6; Khartoum, Sudan. Khartoum, Sudan: Philosophical Society of the Sudan; 1966.

5. Hill DS. Agricultural insect pests of the tropics and their control. London: Cambridge University Press; 1975. 516 p.

6. Tindall HD. Vegetables in the tropics. London: Macmillan Press; 1983. 533 p.

7. Yamaguchi M. World vegetables: principles, production and nutritive values. Westport, (CT): AVI Publishing Company; 1983. 415 p.

8. Sampson AB. Comparisons of three methods for establishing economic threshold levels for Jacobiasca typica (de Berg) on eggplant [dissertation]. [Khartoum, Sudan]: University of Khartoum; 1997.

9. Elkhaliiefa SH. Studies on the biology and ecology of the eggplant fruit-borer Daraba Laisalis (walk) (Lepidoptera: pyralidae) [master's thesis]. [Khartoum, Sudan]: University of Khartoum; 1999. 86 p.

10. Osman ME. Evaluation of eggplant cultivars in the Sudan. Acta Hort. 1984;143:201-4.

11. Olouso MO, Chadha ML. Evaluation of African eggplant for yield and quality characteristics. Acta Hort. 2007;752:303-6.

12. Thanki N, Joshi P, Joshi H. Effect of household processing on reduction of pesticide residues in Brinjal (eggplant, Solanum melongena). Adv Appl Sci Res. 2012;3(5):2860-5.

13. Nesser GA, Abdellahi AO, Hammad AM, Tagelseed M, Laing MD. Levels of pesticide residues in the White Nile water in the Sudan. Environ Monit Assess [Internet]. 2016 Jun [cited 2020 Jan 23];188(6):Article 374. Available from: https://doi.org/10.1007/s10661-016-5367-3 Subscription required to view.

14. Elbashir AA, Abdellahi AO, Hammad AM, Elzorgani GA, Laing MD. Levels of organochlorine pesticides in the blood of people living in areas of intensive pesticide use in Sudan. Environ Monit Assess [Internet]. 2015 Mar [cited 2020 Jan 23];187(3):Article 68. Available from: https://doi.org/10.1007/s10661-015-4269-0 Subscription required to view.

15. Abdellahi AO, Elbashir AB, Hammad AM, Elzorgani GA, Laing MD. Organochlorine levels in human blood from residents in areas of limited pesticide use in Sudan. Toxicol Environ Chem [Internet]. 2015 [cited 2020 Jan 23];97(2):266-73. Available from: https://doi.org/10.1080/02772248.2015.1031669 Subscription required to view.

16. Ahmed RA. Agricultural extension role to reduce the pesticides exposure hazards and their effect: case study, Gezera scheme’s vegetable farmers. [place unknown: publisher unknown];. 2002. Arabic.

17. Mohamed AO, Mater AA, Hammad AM, Ihsag AE, Abdellahi AO, Eldein AM, Eltayeb EM, Dahab AA, Gader AA. Knowledge, attitudes and practices of pesticide sprayers towards pesticides use and handling in greenhouse farms, Sudan. Int J Manag Commer Innov. 2019;6(2):840-50.

18. Mohamed AO, Mater AA, Hammad AM, Ihsag AE, Eldein AM, Eltayeb EM, Dahab AA, Gader AA, Abdellahi AO. Knowledge, attitudes and practices of farmers towards pesticides use and handling in greenhouse farms, Sudan. Int J Res Granthaalayah. 2018 Sep;6(9):520-34.

19. Hammad AM, Abdellahi AO, Ihsag AE Ahmed A, Laing MD. Determination of residues levels of seven pesticides in tomatoes samples taken from three markets in Khartoum State, Sudan. 9th International Conference on Research in Chemical, Agricultural, Biological and Environmental Sciences; 2017 Nov 27-28; Parsy, South Africa. Washington, DC: Conference Publishing Services; 2017. p. 246-9.

20. Hammad AM, Yasein BH, Ihsag AE, Abdellahi AO, Laing MD. Detection of insecticide residues on tomato fruits grown in Khartoum State. Univers Khartoum J Agric Sci. 2015;23(1):49-65.

21. Ahdawi MM, Abdellahi AO, Ihsag AE, Hammad AM. The level of pesticide residues in cucumber fruits collected from central vegetable markets in Khartoum State. EC Pharmacol Toxicol. 2019;7(1):60-8.

22. Musa NH, Hammad AM, Abdellahi AO, Ihsag AE. Pesticides residues in samples of sweet peppers (Capsicum annum) from Khartoum State. Int J Life Sci Res. 2018 Jul-Sep;6(3):472-81.

23. Mohamed AO, Mater AA, Hammad AM, Ihsag AE, El Tayeb EM, Dahab AA. Pesticide residues detected on tomato and cucumber fruits grown in greenhouse farms in Khartoum State, Sudan. Int J Life Sci Res. 2018 Jul-Sep;6(3):472-81.

24. Abdalla KM. Evaluation of field performance of selected insecticides against major pests of tomatoes, associated residues in fruits and farmers knowledge about their use [master’s thesis]. [Khartoum, Sudan]: University of Khartoum; 2005.

25. Codex general standard for contaminants and toxins in food and feed: CODEX STAN 193-1995 [Internet]. Rome: Food and Agriculture Organization of the United Nations; 1995 [updated 2009; cited 2020 Jan 23]. 44 p. Available from: www.fao.org/3/dbs/pestres/en/docs/1_CXS_193e.pdf

26. Kumari B, Madan VK, Kumar R, Kathpal TS. Monitoring of seasonal vegetables for pesticide residues. Environ Monit Assess [Internet]. 2002 Mar [cited 2020 Jan 23];74(3):263-70. Available from: https://doi.org/10.1023/A:1014248827898 Subscription required to view.

27. VO 0440 - Egg plant [cited 2020 Feb 11]. In: Codex Pesticides Residues in Food Online Database [Internet]. Rome: Codex Alimentarius. c2020 - [cited 2020 Feb 11]. Available from: http://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/en/

28. Fanke P, Arnot JA, Doucette WJ. Improving plant bioaccumulation science through consistent reporting of experimental data. J Environ Manage [Internet]. 2016 Oct 1 [cited 2020 Jan 23];181:374-84. Available from: https://doi.org/10.1016/j.jenvman.2016.06.065 Subscription required to view.

29. Codex Pesticides Residues in Food Online Database [Internet]. Rome: Codex Alimentarius. c2020 - [cited 2020 Feb 11]. Available from: http://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/en/

30. Ismail RE. Pesticide residues in eggplant (and evaluation of farmers knowledge about proper use of pesticides in Khartoum State) [master's thesis]. [Khartoum, Sudan]: University of Khartoum; 2016.

31. Regulation (EC) No. 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC.

32. Ahmed MA, Abdellahi AO, Elshafee HA, Fageer EA, Abbass IA. Efficacy of Imidacloprid (Confidor 2005L) and improved cultural practices in the control of the green date palm pit scale insect (Asterolecnum phoinecis Rao.) (Palmapisis phoinecis) (Homoptera: Asterolecaniidae) in northern Sudan. Sci Res Essays. 2013 Oct 4;8(37):1752-8. Subscription required to view.

33. Daraghchmeh A, Shrain A, Abulahj S, Sansour R, Ng JC. Imidacloprid residues in fruits, vegetables and water Samples from Palestine. Environ Geochim Health. 2007 Feb;29(1):45-50.

34. Betwe BO, NtofWJ, Kelderman P, Drechsel P, Carboo D, Ntartey VK, Gijzen HJ. Pesticide residues contamination of vegetables and their public health implications in Ghana. J Environ Issues Agric Dev. 2011 Aug;3(2):10-8.

35. Abdellahi AO. Pesticide use and management in the Sudan. National workshop on insecticide resistance and its management; 2006 Jan 29.
31; Khartoum, Sudan. Geneva: World Health Organization, Federal Ministry of Health; [2006?].
36. Abdalla AT, Satti AM, Yousif G, Moghraby AI. Residues of the organochlorine insecticide endosulfan, in the Gezira Scheme, Sudan. Sudan J Sci. 1985;1:22-9.
37. Assad YO, Bashir HN. Persistent toxic substances (PTS) in the Sudan. Proceedings of the 2nd National Pest Management Conference in the Sudan; Dec 2004 6-9; Wad Medani, Sudan, University of Gezira. [place unknown; publisher unknown]; 2015.
38. Diarra L, Kamissoko M, Alsaffar A, Eldin SM. IPM and pesticide use in Mali and Sudan. Berkeley (CA): Pesticide Action Network North America; 1992 Sep.
39. Alhindi AM. Food contamination, pesticide poisoning episodes and methods of sampling. Training course on the use of pesticides (in Arabic). Khartoum, Sudan: Ministry of Health; 1994.
40. Abdelbagi AO. Assessment of national POPs monitoring and research capacity for persistent organic pollutants (POPs) in the Sudan, their levels in the Sudanese environment, human and animal exposure. Khartoum, Sudan: Ministry of Environment and Physical Development of Sudan; 2005. 38 p.
41. Fantke P, Friedrich R, Jolliet O. Health impact and damage cost assessment of pesticides in Europe. Environ Int [Internet]. 2012 Nov 15 [cited 2020 Jan 23];49:9-17. Available from: https://doi.org/10.1016/j.envint.2012.08.001 Subscription required to view.