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Research Article
Analysis of Pesticide Residues in Lomé Vegetables: Implications for Health and Food Consumption

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Abstract
Background and Objective: In Togo, intensive agriculture practiced in peri-urban areas often involves heavy use of pesticides. This study aims to assess and quantify pesticide residues in market garden products in Lomé and their potential impacts on consumer health. **Materials and Methods:** A survey was carried out among market gardeners in Lomé and samples of vegetables were collected. The samples were analyzed by Gas and Liquid Chromatography Coupled with Tandem Mass Spectrometry (GC-MS/MS and LC-MS/MS) and the daily intake of ingestible residues was determined. The results of the sample analyses were evaluated according to the Maximum Residue Limits (MRLs) of the Codex Alimentarius and the European Commission standards. **Results:** The investigation revealed a lack of control over application methods and the use of several pesticides, including those banned. All samples analyzed contained pesticides. Regarding the estimated quantities of ingestible residues, the results showed that they represented a small proportion of the admissible daily intakes. Pesticides used in market gardening in particular can pose risks to the health of consumers because certain residues are found in these products. Even if these residues are ingested in low doses daily, their regular and long-term ingestion in foods and beverages is a concern, particularly when it comes to pesticides known to cause adverse effects with prolonged exposure. **Conclusion:** In short, from a public health point of view, the observed levels of pesticide residues present a potential health risk for consumers. Long-term studies should be carried out to observe the effects of mixtures of pesticide residues.

Key words: Pesticide residues, vegetables, health risks, EDI (estimated daily intake), MRL (maximum residue limits), market gardening

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Market gardening is a widespread activity in African cities and actively contributes to the balance and dynamics of these cities. From an economic point of view, market gardening is an excellent source of income for residents of urban and peri-urban areas[1,2]; therefore, it plays an important socio-economic role. Market gardeners use phytosanitary products to meet growing demand and achieve profitable production levels, by controlling plant pests, parasitic attacks and fungal diseases. In Lomé, among the plant protection products available, pesticides are the most frequently used[3-5]. Vegetable growers use a variety of pesticides, including insecticides, fungicides and herbicides[6,7]. However, the excessive use of these products is a cause for concern, particularly due to the lack of training and supervision regarding their use in the Coastal Region of Southern Togo[8,9], exposing the population to health risks[4].

Indeed, pesticide use has been associated with several concerns, including potential risks to human health from occupational and non-occupational exposures, death of farm animals and alteration of the local environment[10,11]. Pesticides can cause a range of health problems from minor symptoms such as headaches and dizziness to more serious effects such as CNS and reproductive impacts, genotoxicity, carcinogenicity, mutagenicity and endocrine disruption[12-15]. Many pesticides and their residues are known to be contributing factors to several diseases such as heart disease, Alzheimer's and Parkinson's disease[16]. Pesticide residues can come from pesticides sprayed directly on crops or from soils. Pesticides contaminating the soil can be absorbed by plant roots and transferred to edible parts such as leaves and/or fruits[17,18]. Even after food has been cooked, pesticide residues remain a significant health risk[19,20].

In developing countries, the main tools for monitoring pesticide residues in vegetable products, namely equipment, control programs and training of technical personnel are often lacking[21]. The assessment of pesticide residues in food is crucial for monitoring human exposure to these substances. Usually, these residues are checked against the Maximum Residue Limits (MRLs) established by the Codex Alimentarius[22] and acceptable daily intakes (ADI). A consumer's exposure is of concern if estimated dietary exposure to a pesticide exceeds the ADI.

In Togo, previous studies by Kanda *et al.*[23] and Ahoudi *et al.*[24] reported levels of pesticide residues and their dietary exposure to fruits and vegetables from market gardeners in Lomé. However, monitoring of dietary exposure to pesticide residues must be carried out periodically to ensure the health and safety of market gardeners and to raise consumer awareness. This work also provides an estimate of the risk to human health through the estimated average daily doses (ADI) compared to the ADIs set by the FAO/WHO (2023)[22]. The present study therefore aims to analyze the knowledge, practices and attitudes of market gardeners in Lomé regarding the use of pesticides and to evaluate the levels of pesticide residues in fruits and vegetables collected on the market gardeners' site.

MATERIALS AND METHODS

Study area: The investigations of this study were carried out in Lomé, capital of Togo, in the coastal area. This investigation area, located between the lagoon system and the Atlantic Ocean, is a coastline parallel to the seashore from Baguida to Agbodrafo. It benefits from a sub-equatorial climate with a bi-modal regime. The average annual rainfall is 860 mm/year and the relative humidity is 80 to 90%. The average evapotranspiration is 1540 mm/year and the average temperature varies from 26 to 33°C. Soils developed on coastal sands have poor organic matter and minerals, are permeable and their water reserve is low. The choice of this area was guided not only by the intense activity of market gardening due to the colluvial, hydromorphic, fertile and sandy nature of the soils, but also by the increased use of pesticides[5-7].

Survey of market gardeners: To characterize market gardeners by their methods of use and management of pesticides, a survey was carried out in the study area. This cross-sectional descriptive study was conducted over two months, from February 2023 to March 2023, among market gardeners. The choice of respondents was made using the systematic sampling technique. The information was obtained using a standardized questionnaire. During this exercise, emphasis was placed on gender, age, level of education, market gardening training, protection during treatment, pesticide application methods, discomfort following pesticide application, the pesticides used and the time before harvest observed by the market gardener.

Pesticide residue content: To measure the impact of the use of pesticides on vegetables produced by market gardeners in Lomé, samples ready for sale were taken at random from different points of the market gardening areas. A total of 10 vegetable samples were collected in 3 copies (Table 1). During sampling, dead plant parts were immediately removed and the samples were packaged in a cooler before being sent to the regional food safety laboratory for expertise and analysis of IRGIB AFRICA University in Cotonou (Benin) for pesticide dose assessment.

Table 1: List of vegetables collected from growers

Vegetable	Scientific name
Okra	*Hibiscus esculentus*
Carrot	*Daucus carota*
African spinach (Gboma)	*Solanum aethiopicum*
Lettuce	*Lactuca sativa*
Jute mallow	*Corchorus olitorius*
Onion	*Allium cepa*
Bird pepper	*Capsicum frutescens*
Cucumber	*Cucumis sativus*
Beetroot	*Beta vulgaris* subsp. *vulgaris*
Tomato	*Lycopersicum esculentum*

Table 2: Pesticides to be measured in vegetable samples

Chemical group	Pesticide	Class
Carbamates	Carbon disulfide	Fungicide
	Mancozeb	Fungicide
	Maneb	Fungicide
	Carbofuran	Insecticide
Pyrethroids	Cypermethrin	Insecticide
	Deltamethrin	Insecticide
	Lambda-Cyhalothrin	Insecticide
Organophosphates	Glyphosate	Herbicide
	Chlorpyrifos-Ethyl	Insecticide
Avermectins	Abamectin	Insecticide
	Emamectin-Benzoate	Insecticide
Dinitroanilines	Pendimethalin	Herbicide
Pyridine derivatives	Paraquat	Herbicide
Organochlorines	Endosulfan	Insecticide

A total of 14 pesticides (Table 2) were tested in the vegetable samples. These pesticides were chosen based on the results reported by the current survey and previous studies of Kanda *et al.*[23] and Ahoudi *et al.*[24].

Analysis of pesticide residues: For the dose of pesticides, the analyses were carried out by Gas and Liquid Chromatography Coupled with Tandem Mass Spectrometry (GC-MS/MS and LC-MS/MS) from Thermo Fisher Scientific. Determination of pesticide residues using gas and liquid chromatography-mass spectrometry analysis was performed following the acetonitrile extraction/partitioning and clean-up by dispersive SPE-QuEChERS-method (quick, easy, cheap, effective, rugged and safe). This method involves liquid-liquid partitioning using acetonitrile and purifying the extract using dispersive solid-phase extraction.

The general procedure consisted of using a quantity of 10 ± 0.1 g previously homogenized for extraction with acetonitrile (10 mL). After addition of a mixture of salts composed of 4 g of magnesium sulfate, 1 g of sodium chloride, 1 g of trisodium citrate dihydrate and 0.5 g of disodium hydrogen citrate sesquihydrate, the mixture was shaken and centrifuged for phase separation at 3000 rpm for 5 min. An aliquot of the organic phase (6 mL) was transferred into a polypropylene tube containing 150 mg of primary and secondary amines (PSA), 900 mg of magnesium sulfate and 45 mg of carbon black was vigorously shaken for 2 min then centrifuged at 3000 rpm for 5 min. A 4 mL aliquot of the extract purified and acidified with 5% formic acid in acetonitrile (10 µL per mL of extract) was introduced into a pillbox and concentrated to dryness under a weak stream of nitrogen. The extracts are subjected to the gas and liquid chromatography-mass spectrometry analysis. An extraction described by Pizzutti *et al.*[25] has been carried out for paraquat.

Evaluation of the dose of pesticide ingested: Generally, the intake of pesticide residues per day per person was calculated by taking into account correction factors (cooking), which affect the level of pesticide residues in table foods[26]. In the absence of this correction factor at the local level, the daily ingestion of pesticide residues was evaluated based on the average consumption of each of the foods reported by Ahoudi *et al.*[24] and for tomatoes by Son *et al.*[27].

The risk assessment of pesticide residues in food is based on the toxicological assessment of single compounds and multiple compounds and exposure to multiple pesticide residues in food crops, vegetables and fruits. The risk assessment of pesticide residues on consumers is done by taking into account:

- Hypothetical body weight of 10 kg for children and 70 kg for adults
- Maximum absorption rate of 100% and the bioavailability rate of 100%
- And the level of pesticide residues (the average)

For each type of exposure, the estimated daily intake of EDI (estimated daily intake) of pesticide residue was calculated as follows:

$$\text{Food EDI (mg/kg of body weight/day)} = \text{LR} \times \text{QFI}$$

where, LR is the level of pesticide residues in ingested food (mg/kg):

$$\text{QFI} = \frac{\text{Average consumption of food}}{\text{Body weight (adult)}}$$

where, QFI is quantity of food ingested (kg/kg of body weight/day).

The health risk indices (HRI) for chronic exposure of adults and children were calculated as ratios between the estimated daily intake (EDI) doses of pesticide residues and the reference acceptable daily intake (ADI) which are considered to be safe exposure levels throughout life:

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

When this quotient exceeds one (EDI>ADI) this indicates a risk. When more than one residue is present, the HRI of pesticides with a common mode of action was added to account for cumulative toxicity[28].

RESULTS

Survey data

Sociodemographic profile of market gardeners: In total, 88 market gardeners were interviewed across the site and their sociodemographic profile was presented in Table 3. Market gardening activity is carried out mainly by men (93.2%) with a sex ratio (M/F) of 13.6 as shown in Table 3. The mean age of the respondents was 41.3 years with a standard deviation of 13.1. The dominant age group is between 40 and 50 years old with a percentage of 31.8. Furthermore, 48.9% of market gardeners had a primary education level and few were illiterate (10.2%). Regarding experience in the profession, 38.6% of respondents had less than 10 years of experience and 31.8% respondents had between 10 and 20 years of experience.

Knowledge, attitudes and practices of market gardeners related to the use of pesticides: Abamectin, lambda-cyhalothrin, mancozeb, pendimethalin and glyphosate represented the most present active substances in the pesticides used with percentages of 20.1, 17.4, 12.3, 11. 8 and 10.5% respectively (Fig. 1). Few market gardeners (37.5%) had training on the use of pesticides (Table 4). Majority of market gardeners (84.1%) mixed pesticides before applying them. Figure 2 presented the most found double substances in the mixtures. Lambda-cyhalothrin+mancozeb was the most predominant combination in the mixtures with a frequency of 16, followed by that of abamectin+glyphosate and abamectin+chlorpyrifos-ethyl. Among the mixtures, hydrocarbons such as petroleum were also found mixed with pesticides, namely mancozeb (Fig. 3). When spraying pesticides, the majority of market gardeners (56.8%) did not wear protective equipment (suits, appropriate masks, gloves, glasses, or boots) (Table 4). The use of protective masks was the most reported (84.2%) as a means of protection, followed by boots (68.4%) and gloves (36.8%). After using phytosanitary products, 68.2% of market gardeners throw away the packaging and 30.7% burn it (Table 4). The preharvest interval (PHI) of market garden products was mainly between 14 and 21 days (60.2%) after pesticide spraying. The majority of market gardeners (42.0%) were helped by children under 12 years old. The majority of market gardeners surveyed (88.6%) perceived the risks to human health due to the handling of chemical pesticides (Table 5). Some health problems linked to the use of phytosanitary products were mentioned (Table 5). Heat/burning sensation, tingling fingers and dizziness were the most frequently reported symptoms by respondents. Only 4.5% of market gardeners sought treatment if they felt unwell. The majority (65.9%) took a shower or washed themselves if they felt unwell.

Pesticide residue content in vegetables: Laboratory analyses were carried out on 10 vegetable samples in triplicates (30) in search of active substances and pesticide metabolites. The levels of pesticides present in the samples vary from 0.00183 to 1.0703 mg/kg (Table 6). All samples contained pesticide residues. Of the 140 pesticide residue results reported, 30 (21.4%) were non-detectable (ND), 25 (17.9%) had results above the Maximum Residue Limits (MRLS) and 85 (60.7%)

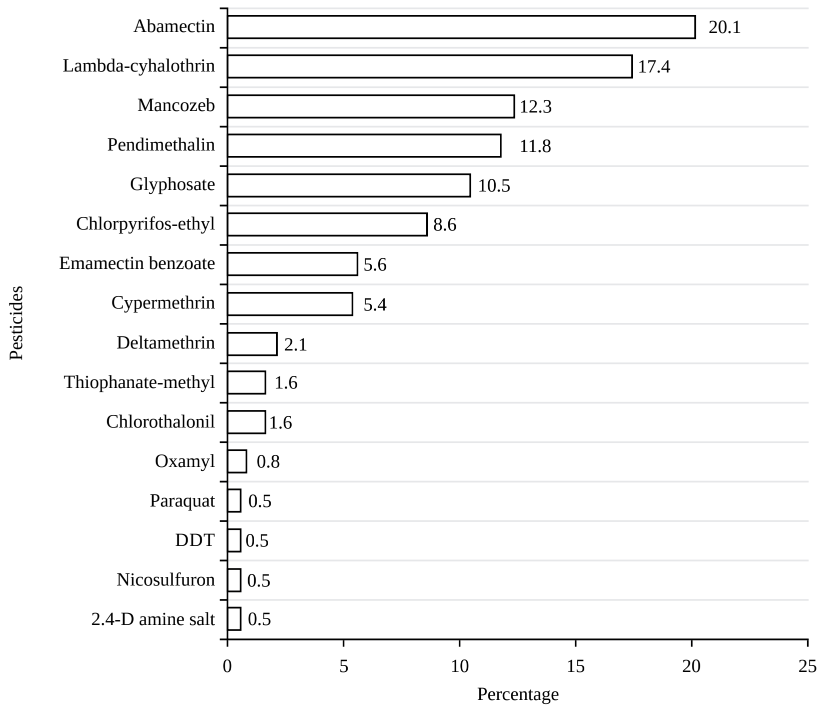

Fig. 1: Frequency of active substances present in pesticides used by market gardeners on the togolese coast
DDT: Dichlorodiphenyltrichloroethane and 2,4-D amine salt: 2,4-dichlorophenoxy acetic acid dimethyl amine salt

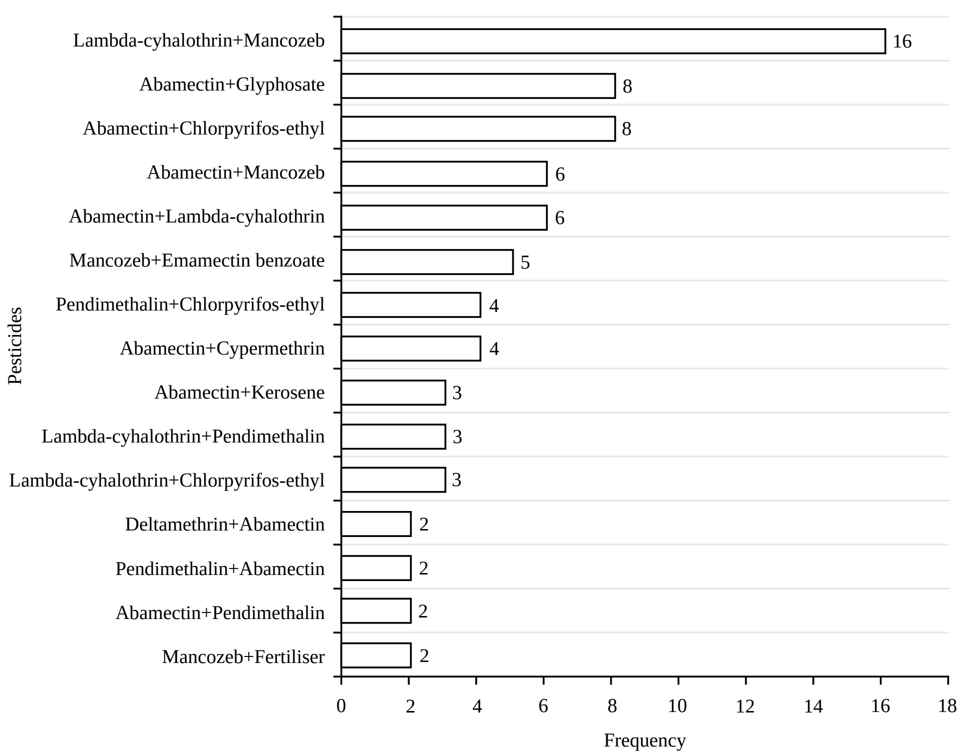

Fig. 2: Distribution of the most frequently found double substances in mixtures

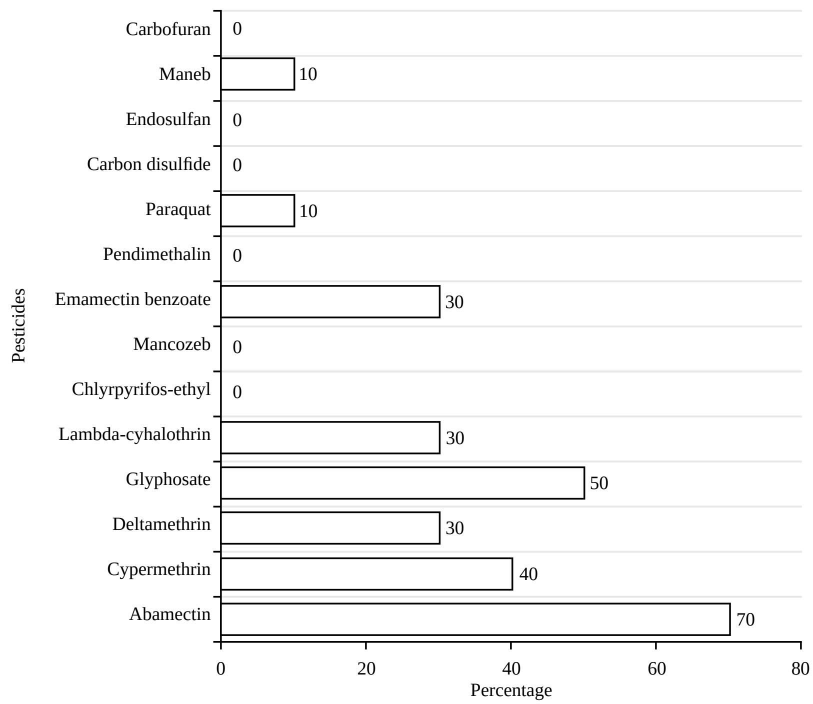

Fig. 3: Frequency of pesticide levels above the maximum residue limit in vegetable samples

Table 3: Distribution by sociodemographic profile of 88 market gardeners surveyed on the Togolese Coast

	Frequency	Percentage
Sex		
Male	82	93.2
Female	6	6.8
Age range (years)		
<30	16	18.2
30-40	19	21.6
40-50	28	31.8
≥50	25	28.4
Education level		
Uneducated	9	10.2
Primary	43	48.9
Secondary	36	40.9
Number of years in the profession (years)		
<10	34	38.6
10-20	28	31.8
≥20	26	29.6

were within Codex Alimentarius and EU standards. Each sample contained at least one active pesticide substance whose level exceeded the MRL. Of the 14 pesticides measured, more than 9 were detected in each sample. Abamectin was the most detected pesticide in samples with levels that exceeded maximum residue limits (70%) (Fig. 3), in okra, carrots, Jewish mallow, onions, cucumbers, beets and tomatoes (Table 6). Glyphosate was in second place (50%) with concentrations that exceeded the MRL in okra, African spinach (gboma), lettuce, onion and tomato respectively at 0.187, 0.513, 0.267, 0.108 and 0.301 mg/kg. Paraquat was detected in all samples. The residue level of deltamethrin was above the MRL in carrot (0.435 mg/kg), African spinach (0.732 mg/kg) and beetroot (0.639 mg/kg). Lambda-cyhalothrin (0.243 mg/kg) was detected above the MRL of 0.1 mg/kg in okra. The cumulative health risk assessment (Table 7) associated with exposure to pesticides in vegetables is less than 100% ADI.

Table 4: Distribution of market gardeners according to pesticide practice items on the Togolese Coast

	Frequency	Percentage
Training (n = 88)		
Yes	33	37.5
No	55	62.5
Mixing pesticides (n = 88)		
Yes	74	84.1
No	14	15.9
Practicing protection during application (n = 88)		
Yes	38	43.2
No	50	56.8
Means of protection during application n = 38		
Gloves	14	36.8
Masks	32	84.2
Boots	26	68.4
Goggles	3	7.9
Coveralls (PPE)	1	2.6
Management of packaging (n = 88)		
Reused	12	13.6
Discarded	60	68.2
Buried	4	4.5
Burnt	27	30.7
PHI (n = 88)		
Less than 7 days	7	7.9
7 to 14 days	21	24
14 to 21 days	53	60.2
More than 21 days	7	7.9
Helpers (n = 88)		
Children under 12 years old	37	42.0
Women	25	28.4

Table 5: Distribution of market gardeners according to attitudinal parameters related to pesticide health risks

	Frequency	Percentage
Level of risk perception (n = 80)		
High	78	88.6
Not high	10	11.4
Discomforts linked to the application of pesticides (n = 88)		
Dizziness	8	9.1
Nasal congestion and cold	1	1.1
Red eyes	1	1.1
Nausea and vomiting	3	3.4
Coughing	2	2.3
Tingling fingers	12	13.6
Heat/skin burn	48	54.5
Attitudes adopted in the event of discomfort (n = 88)		
Take a shower immediately/wash hands	58	65.9
Drink milk/red palm oil	18	20.5
Seek treatment/take pills	4	4.5

DISCUSSION

This study showed that market gardening in Lomé was largely dominated by men representing 93.2% of producers. These results supported those of Diallo *et al.*[5] and Mensah *et al.*[7], who respectively reported 70.8 and 78% males in the population of market gardeners in Lomé. Low percentages of women were also reported by Kpan *et al.*[29] in Ivory Coast and by Muliele *et al.*[30] in Congo. This low percentage of women could be explained by the fact that they were more involved in the marketing of market garden products. The majority of market gardeners had a high education attainment rate (89.8%). This high education attainment rate would therefore constitute an asset, especially since a high illiteracy rate would constitute, according to the studies of Kanda *et al.*[4] and Diallo *et al.*[5] an obstacle to good knowledge of the terms of use of pesticides, because the labels are always in French. On the other hand, the low illiteracy rate and the lack of qualifying training reported by the study would explain the non-compliance with good agricultural practices. These market gardeners therefore run a higher risk when using pesticides, due to difficulties in understanding the instructions for use and safety procedures on product labels[31].

Table 6: Pesticide concentrations in vegetable samples

Measured pesticides	(mg/kg)	Okra	Carrot	African spinach (Gboma)	Lettuce	Jute mallow	Onion	Pepper	Cucumber	Beetroot	Tomato
Abamectin	Mean	0.035	0.131	UD	UD	0.0117	0.061	UD	0.3050	0.1870	0.2053
	MRL	0.01	0.01	-	-	0.01	0.01	-	0.02	0.01	0.015
Cypermethrin	Mean	0.00183	0.2193	0.5210	0.7312	0.0649	0.1815	0.3130	1.0703	0.7181	0.0731
	MRL	0.5	0.7	-	0.7	-	0.01	2	0.7	0.1	0.2
Deltamethrin	Mean	0.0235	0.4350	0.7323	0.0936	0.0312	0.0813	0.1003	0.0721	0.6395	0.1530
	MRL	0.3	0.02	0.5	0.5	0.2	0.1	0.2	0.2	0.05	-
Glyphosate	Mean	0.187	0.0219	0.5135	0.2671	0.0130	0.1079	0.0821	0.0135	0.0143	0.3014
	MRL	0.1	0.1	0.1	0.1	-	0.1		0.1	0.1	0.1
Lambda-Cyhalothrin	Mean	0.2428	0.0233	0.0932	0.0274	UD	0.0523	0.0127	0.3741	0.2790	0.0219
	MRL	0.1	0.2	0.5	0.5	-	0.2	0.3	0.05	0.2	0.1
Chlorpyriphos-Ethyl	Mean	0.0063	UD	0.5135	0.0201	0.0187	0.0320	0.1512	0.0189	0.4350	UD
	MRL	0.5	-	-	0.05	-	0.2	-	0.05	-	-
Mancozeb	Mean	0.0125	0.0874	0.0205	0.0189	UD	0.0668	0.1002	0.0272	0.0625	0.0137
	MRL	-	0.2	-	0.05	-	1	-	2	0.5	3
Emamectin benzoate	Mean	0.0287	UD	UD	0.0132	0.2150	0.0061	0.23	UD	0.0069	0.0103
	MRL	0.02	-	-	1	0.2	0.01	0.02	0.01	0.01	0.02
Pendimethalin	Mean	0.0139	0.0210	0.0137	0.0054	UD	0.1357	0.2170	UD	0.1031	UD
	MRL	-	0.5	-	4	-	0.05	-	-	-	-
Paraquat	Mean	0.3710	0.1613	0.0952	0.0371	0.0713	0.2135	0.0109	0.1830	0.0038	0.1035
	MRL	-	-	0.07	0.07	-	-	-	-	0.07	-
Carbon disulfide	Mean	UD	UD	UD	UD	UD	0.0031	UD	UD	UD	UD
	MRL	-	-	-	-	-	0.5	-	-	-	-
Endosulfan	Mean	0.0211	UD	UD	0.0073	0.0187	0.0021	0.0063	UD	UD	0.0079
	MRL	-	-	-	-	-	-	-	-	-	0.5
Maneb	Mean	0.8019	0.3187	0.1251	0.1043	0.2001	0.0107	0.3720	0.0057	0.1710	0.1271
	MRL	5	1	-	0.05	-	-	-	2	0.5	2
Carbofuran	Mean	0.0107	UD	UD	UD	0.0817	0.3151	0.8072	1.0307	0.1023	UD
	MRL	-	-	-	-	-	-	-	-	0.2	0.01

Mean: Pesticide residue levels detected, MRL: Maximum residue limit and UD: Undetectable

Table 7: Parameters for assessing exposure to pesticide residues detected in vegetable samples

		Okra		Carrot		Gboma (African spinach)		Lettuce		Jute mallow	
	ADI	EDI	HRI	EDI	HRI	EDI	HRI	EDI	HRI	EDI	HRI
Carbamates											
Carbon disulfide	0.003	-	-	-	-	-	-	-	-	-	-
Mancozeb	0.03	2.02E-05	0.00067	2.1E-05	0.00071	2.6E-06	8.8E-05	3.8E-06	0.00013	-	-
Maneb	0.03	0.001294	0.04315	7.7E-05	0.00258	1.6E-05	0.00054	2.1E-05	0.0007	5.7E-05	0.00191
Carbofuran	-			-	-	-	-	-	-	2.3E-05	-
∑HRI			0.04382		0.00329		0.00062		0.00082		0.00191
Pyrethroids											
Cypermethrin	0.02	2.95E-06	0.00015	5.3E-05	0.00266	6.7E-05	0.00335	0.00015	0.00731	1.9E-05	0.00093
Deltamethrin	0.01	3.79E-05	0.00379	0.00011	0.01056	9.4E-05	0.00942	1.9E-05	0.00187	8.9E-06	0.00089
Lambda-cyhalothrin	0.02	0.000392	0.0196	5.7E-06	0.00028	1.2E-05	0.0006	5.5E-06	0.00027	-	-
∑HRI			0.02354		0.01351		0.01336		0.00946		0.00182
Organophosphates											
Glyphosate	1	0.000302	0.0003	5.3E-06	5.3E-06	6.6E-05	6.6E-05	5.3E-05	5.3E-05	3.7E-06	3.7E-06
Chlorpyrifos-ethyl	0.01	1.02E-05	0.00102	-	-	6.6E-05	0.0066	4E-06	0.0004	5.3E-06	0.00053
∑HRI			0.00132		5.3E-06		0.00667		0.00046		0.00054
Avermectins											
Abamectin	0.001	5.65E-05	0.0565	3.2E-05	0.03181	-	-	-	-	3.3E-06	0.00334
Emamectin benzoate	0.0005	4.63E-05	0.09266	-	-	-	-	2.6E-06	0.00528	6.1E-05	0.12286
∑HRI			0.14916		0.03181	-	-		0.00528		0.1262
Pendimethalin (Dinitroaniline)	0.1	2.24E-05	0.00022	5.1E-06	5.1E-05	1.8E-06	1.8E-05	1.1E-06	1.1E-05	-	-
Paraquat (Pyridine)	0.005	0.000599	0.11978	3.9E-05	0.00783	1.2E-05	0.00245	7.4E-06	0.00148	2E-05	0.00407
Endosulfan (Organochlorine)	0.006	3.41E-05	0.00568	-	-	-	-	1.5E-06	0.00024	5.3E-06	0.00089

		Onion		Pepper		Cucumber		Beetroot		Tomato	
	ADI	EDI	HRI	EDI	HRI	EDI	HRI	EDI	HRI	EDI	HRI
Carbamates											
Carbon disulfide	0.003	1.8E-07	5.9E-05	-	-	-	-	-	-		-
Mancozeb	0.03	3.8E-06	0.00013	2.9E-06	9.5E-05	1,2E-07	4.1E-06	1.2E-05	0.00039	3E-05	0.0011
Maneb	0.03	6.1E-07	2E-05	1.1E-05	0.00035	2,6E-08	8.7E-07	3.2E-05	0.00106	0.0003	0.0103
Carbofuran	-	1.8E-05	-	2.3E-05	-	4.7E-06	-	1.9E-05	-	-	-
∑HRI			0.00021		0.00045		5E-06		0.00145		0.0114
Pyrethroids											
Cypermethrin	0.02	1E-05	0.00052	8.9E-06	0.00045	4.9E-06	0.00024	0.00013	0.00667	0.0002	0.0089
Deltamethrin	0.01	4.6E-06	0.00046	2.9E-06	0.00029	3.3E-07	3.3E-05	0.00012	0.01188	0.0004	0.0372
Lambda-cyhalothrin	0.02	3E-06	0.00015	3.6E-07	1.8E-05	1.7E-06	8.6E-05	5.2E-05	0.00259	5E-05	0.0027
∑HRI			0.00113		0.00075		0.00036		0.02114		0.0487
Organophosphates											
Glyphosate	1	6.2E-06	6.2E-06	0.00016	0.00016	6.2E-08	6.2E-08	2.7E-06	2.7E-06	0.0007	0.0007
Chlorpyrifos-ethyl	0.01	1.8E-06	0.00018	4.3E-06	0.00043	8.6E-08	8.6E-06	8.1E-05	0.00808	-	-
∑HRI			0.00019		0.0006		8.7E-06		0.00808		0.00049
Avermectins											
Abamectin	0.001	3.5E-06	0.00349	-	-	1.4E-06	0.00139	3.5E-05	0.03473	0.0005	0.4986
Emamectin benzoate	0.0005	3.5E-07	0.0007	6.6E-06	0.01314	-	-	1.3E-06	0.00256	3E-05	0.05
∑HRI			0.00418		0.01314		0.00139		0.03729		0.5486
Pendimethalin (Dinitroaniline)	0.1	2E-06	2E-05	6.2E-06	6.2E-05	-	-	1.9E-05	0.00019	-	-
Paraquat (Pyridine)	0.005	1.2E-05	0.00244	3.1E-07	6.2E-05	8.4E-07	0.00017	7.1E-07	0.00014	0.0003	0.0503
Endosulfan (Organochlorine)	0.006	1.2E-07	0.00002	1.8E-07	0.00003	-	-	-	-	2E-05	0.0032

ADI (mg/kg): Acceptable daily intake, EDI (mg/kg): Estimated daily intake, HRI (%): Health risk index (%) = EDI/ADI×100 and ∑HRI: Sum of risk indices by chemical group

Far from the assumption that one might make by thinking that seniority in the use of pesticides confers a certain experience, this study revealed that certain people with many years of use did not set a good example. They carried out the application without any precautions. The same observation was reported by Bernard *et al.*[32] in Cameroon. Poor management of pesticide packaging poses risks of environmental contamination, particularly water contamination. The contamination of surface waters by the gaseous deposition of pesticides volatilized from treatment areas having now been proven[33], could increase the presence of chemicals in groundwater in Lomé.

The active ingredients present in the products listed, classified according to the WHO toxicity scale[34], are mainly in classes II and III, although there are also class I substances (abamectin and oxamyl). Class II (including cypermethrin, deltamethrin, lambda-cyhalothrin, emamectin-benzoate, pendimethalin, paraquat and DDT) corresponds to moderately hazardous pesticides, underlining the need for handling by well-trained and informed individuals. However, our study population which handles pesticides was characterized by a low level of education and a lack of training on the use of pesticides. Class III (Glyphosate) of low-risk pesticides could be used by market gardeners. Among the class I pesticides, the active substance abamectin was the most present in the pesticides used. The inappropriate use of phytosanitary products constitutes a major potential exposure risk factor for market gardeners and consumers. The prevalence of mixing two pesticides was very high in our study. This practice could endanger the population due to the synergistic or potentiating effect of chemical residues[35,36].

Considering the results of the survey, it appears important to push the analyses forward by carrying out dosing of pesticide residues on some of the most cultivated market garden crops to optimally evaluate the quality of the vegetables and the potential risks to human health. Most health effects of pesticides in humans are due to direct exposure either occupationally for agricultural workers who apply pesticides or through self-intoxication[10,11]. Additionally, health effects can be demonstrated through indirect dietary exposure[37]. The analysis revealed the presence of pesticide residues in the vegetables. All the samples tested presented, at different concentrations, a minimum of 5 pesticide residues out of the 14 searched for. Previous studies have already reported the presence of several pesticide residues in vegetables[23,24]. The presence of certain active substances in the samples other than those reported by the investigation reveals that other pesticides not listed by the market gardeners were used. This presence could be due to indirect contamination of crops or to the hiding of information by market gardeners during the investigation. Indeed, when treating a plot, under the action of the wind, a certain quantity of pesticides could be transferred onto neighboring plots[27]. A study carried out by Xue *et al.*[38] also confirmed the effect of wind on the transport of pesticides in the form of particles, vapor, or droplets. This means that they can be carried over a long distance from their source and subsequently absorbed by vegetation to end up in the food chain.

Comparing the levels of pesticide residues with the various corresponding MRLs highlighted that the concentration of certain pesticide residues is higher than the MRLs authorized by the Codex Alimentarius[22] and those of the EU (European Union)[39] in cases where there are no Codex specified MRLs. Abamectin, the most widely used systemic insecticide to combat various vegetable pests as reported by our survey, is the active substance whose concentration is above the MRL in all tested samples (70%). As a biopesticide, abamectin is a substance harmful to the human body. Studies have reported effects on kidney[40], liver[41] and brain[42] function. Pesticides classified as moderately hazardous (class III) were detected in all samples. Among the pesticide residues tested, glyphosate and paraquat were detected in the samples. Because of their extremely harmful effects on human and animal health and their long-term persistence in the environment, their import, marketing and use were banned in Togo by Decrees no. 0078/18 and 183/19 issued by the Ministry of Agriculture, Animal Production and Fisheries However, these pesticides are still used clandestinely in Togo as reported by the results of the analysis. Glyphosate is a widely used herbicide with broad-spectrum activity. Despite its ban, it was detected in all samples, with concentrations above the MRL in half of the samples. This herbicide affects the development of the human nervous system[43,44] reproduction[45,46] and the endocrine system[47]. An insecticide such as cypermethrin which was present in all samples, was detected at a concentration above the MRL in lettuce, onion, beetroot and cucumber. In contrast, Salem *et al.*[48] revealed cypermethrin concentrations below the MRL in green dill and tomatoes. Chlorpyrifos, an organophosphate insecticide, was detected in Lomé by Ahoudi *et al.*[24] in three types of vegetables (spinach, bell pepper and cucumber) at concentrations above the MRL. However, in our study, chlorpyrifos was detected in all vegetables, but at concentrations lower than the MRL. Meanwhile, the herbicide deltamethrin was detected in all vegetables and the highest concentration was recorded in carrot (0.43 mg/kg), African spinach (Gboma) leaves (0.73 mg/kg) and beetroot (0.63 mg/kg). Compared to previous studies, chlorpyrifos was detected only in chili pepper at a concentration below the MRL[24].

The presence of pesticide residues in vegetables may be due to growers' lack of awareness about dosages, correct application methods and the appropriate interval between harvest and pesticide treatment. Negligence or lack of proper guidance regarding pesticide application may be another reason for the presence of pesticide residues in vegetable samples. Even moderate contamination of food products by pesticides associated with continued consumption of these food products can have negative consequences on human health in the long term[49]. Pesticides can accumulate in the tissues of organisms because they are not easily soluble[50]. Thus, misuse or excessive use of pesticides without any prior guidance and knowledge has become a serious public health issue.

As a general rule, European and Codex standards set safety thresholds to protect consumers well below permissible limits. However, risk assessment is based on toxicological parameters such as acceptable daily intakes (ADIs)[51]. A comparison of the results obtained with individual ADIs indicates that the risk associated with the consumption of vegetables from our study site is very low.

Faced with the increase in cases of pest resistance, professionals are increasingly turning to the combined use of a large number of pesticides at the same time or sequentially in the integrated fight against vectors and pests[52]. The excessive use and reckless combination of various pesticides in Lomé and other Sub-Saharan countries has previously given rise to serious concern[4,8]. Thus, the current study observed the presence of multiple residues in each sample analyzed. The occurrence of contamination with multi-residue pesticides in different products has also been reported by Selim *et al.*[53]. Indeed, the concentrations of individual pesticides found as residues in a single food are often far from reaching the dose likely to cause immediate acute poisoning. However, continuous consumption over a long period of trace amounts of various pesticides in foods and beverages raises concerns, particularly those pesticides known to have adverse effects from prolonged exposure[9,11,54]. Studies have indicated that repeated exposure, compounded by the cumulative effects of certain substances, may pose long-term risks, potentially leading to conditions such as immunodeficiencies, neurological deficits, reproductive disorders, behavioral disorders and cancer development. Added to these are uncertainties regarding the effects of mixtures of different pesticide residues, which can interact in the body and exacerbate the damage. Therefore, a study assessing exposure to pesticide mixtures would be particularly relevant. Recent scientific work by Rouimi *et al.*[55] on the effects of very low doses of pesticides suggests that current safety levels should be much stricter to adequately protect human health, particularly that of children and other vulnerable adult groups.

CONCLUSION

The present study examined the phytosanitary practices of market gardeners and the levels of pesticide residues in vegetables used in Lomé. The results revealed non-compliance with good pesticide use practices. The intervals before harvesting market garden crops are not respected by producers. The phytosanitary practices observed by Lomé market gardeners result in the non-compliance of the samples. The majority of vegetable samples were contaminated with pesticide residues, with concentrations above the MRLs. From a public health perspective, the observed levels of pesticide residues present a potential risk to the health of consumers. Therefore, to reduce this risk, special attention should be given to developing pesticide reduction strategies in market gardening through training market gardeners in the judicious and safe use of pesticides and promoting alternatives to chemical control of pests such as biological control. Raising market gardeners' awareness of better safety practices about pesticide use and the need for continuous monitoring of pesticide residues is strongly recommended. Under such conditions, the probability of knowing pesticides and their ecotoxicity well was minimal and ignorance of chronic dangers could explain the non-use of protective equipment by market gardeners.

SIGNIFICANCE STATEMENT

The study of "market for market garden produce in Lomé: pesticide residues and health risks" was necessary for several crucial reasons. Firstly, it aimed to systematically assess and document the presence of pesticide residues in market garden produce sold in Lomé, a public health issue of growing concern in developing urban areas. Secondly, the study has made a unique contribution by using advanced analytical methods to precisely quantify and identify the pesticides present, thus providing an in-depth understanding of the potential health risks associated with these residues. Finally, by highlighting contamination levels and discussing implications for human health, the study has enriched the academic corpus on food safety and the impacts of agricultural practices on the urban environment in Sub-Saharan contexts.

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