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Analysis of current chemical risks associated with vegetables in the commune of Yopougon following the application of various treatment methods

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Abstract

This study evaluates the chemical risks linked to pesticide residues in vegetables from Yopougon (Côte d'Ivoire) and the effectiveness of washing methods to reduce these contaminants. The context reveals alarming contamination due to the intensive use of pesticides in urban agriculture, threatening consumer health through acute and chronic effects. The general objective is to compare three washing methods: sodium hypochlorite (1%, 5 min), sodium bicarbonate (1%, 10 min in ice-cold water), and their combination (5 min), on samples of lettuce, tomato, cucumber, and pepper analyzed by HPLC according to the NF EN 12393-3 standard. The results show that the combined method is the most effective, reducing residues by over 90%, compared to 49-87% for individual methods. However, pesticides such as ethyl-parathion and diuron persist, presenting high health risks (QD > 1). The conclusion emphasizes the need to combine preventive measures (pesticide reduction) and curative measures (optimized washing) to improve food safety. The outlook includes promoting sustainable agricultural practices and raising awareness among local stakeholders to minimize exposure to toxic residues.

Keywords: Pesticide Residues; Contamination; Washing; Health Risk; Yopougon

1. Introduction

Urban vegetable farming, which accounts for approximately 33% of global agricultural production and engages nearly 800 million people, plays a crucial socio-economic role, particularly in Côte d'Ivoire. In Abidjan, green spaces and lowlands are intensively cultivated for vegetable production, generating essential income for vulnerable populations in peri-urban areas (El-Sheikh et al., 2022; Gueye et al., 2020). However, the sanitary quality of these products is often compromised by the excessive use of pesticides, leading to chemical pollution and the presence of residues hazardous to human health (Ssemugabo et al., 2023). These residues can cause acute effects (dizziness, headaches) and chronic effects (cancers, endocrine disruptions) (Wanwimolruk et al., 2015; Ibrahim et al., 2018).

Despite these risks, there is a lack of awareness among producers and consumers regarding the dangers of chemical contamination, exacerbating the situation (Ssemugabo et al., 2023). Studies reveal significant contamination of fruits and vegetables, with up to 63.3% of samples exceeding Maximum Residue Limits (MRLs) (El-Sheikh et al., 2022; Mwanja et al., 2017). The chemical families of organochlorines and organophosphates, particularly stable and toxic, represent

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a major health risk, necessitating rigorous controls to ensure admissible residue levels and prevent misuse (El-Sheikh et al., 2022).

It is therefore imperative to strengthen awareness and education among producers and consumers to minimize exposure to pesticide residues (Ssemugabo et al., 2023; Ibrahim et al., 2018). The adoption of sustainable agricultural practices and adherence to good phytosanitary practices are essential to mitigate this public health issue in the vegetable farming sector (Mazlan et al., 2017).

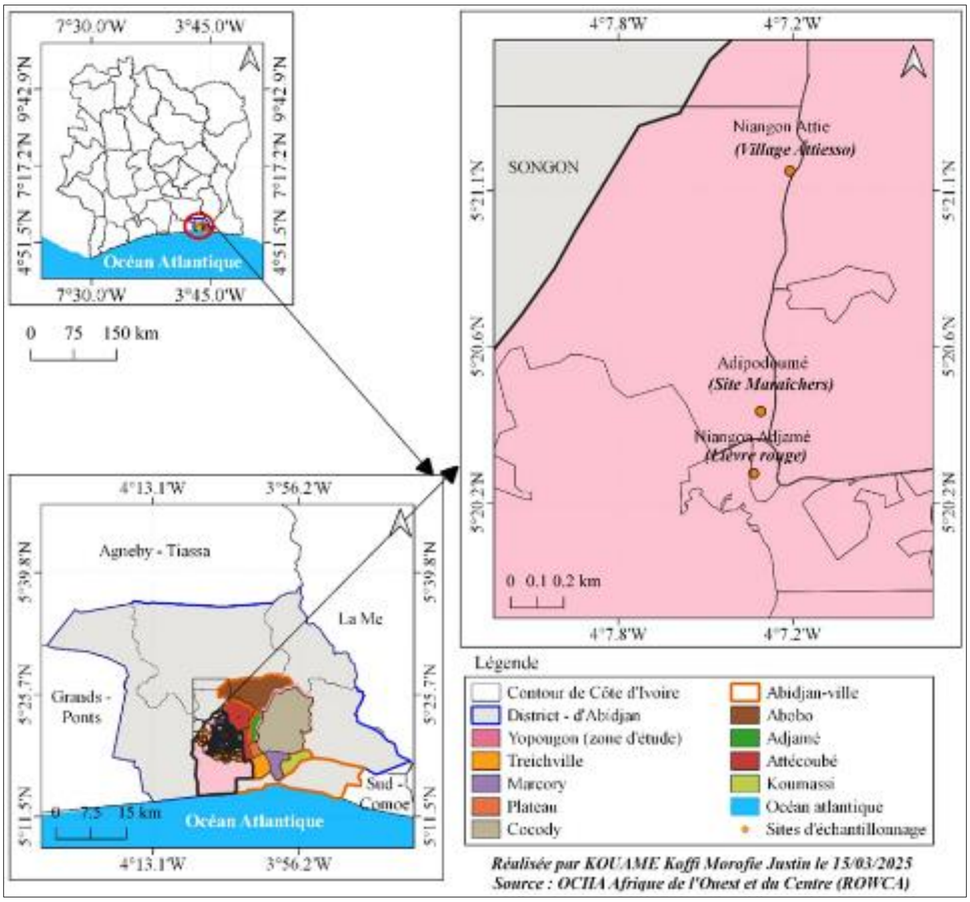
Facing these challenges, this study aims to evaluate the effectiveness of different washing methods (sodium bicarbonate, sodium hypochlorite, or a combination of both) in reducing pesticide residues in cucumbers, tomatoes, peppers, and lettuce produced in Yopougon.

The objective is to improve the sanitary quality of vegetable products and raise consumer awareness of proper washing practices to limit health risks

2. Material and methods

2.1. Study Site

The study was conducted in the autonomous district of Abidjan, specifically in the commune of Yopougon, located between the Banco Forest and the Ebrié Lagoon, west of the northern geographical zone of Abidjan. The geographical coordinates of the commune are 5°20'56" North and 4°00'42" West. It has a population of 1,571,065 inhabitants, with a density of 9,568 inhabitants/km², and covers an area of 16,420 hectares (164.2 km²). Its altitude ranges from 40 to 132 meters above sea level.



Directed by KOUAME Koffi Morofie Justin on 12/12/2023 Source: OCHA West and Africa (ROWCA)

Figure 1 Location of vegetable production areas in the yopougon municipality

2.2. Study Material

The study focused on samples of lettuce (*Lactuca sativa*), tomato (*Lycopersicon esculentum*), cucumber (*Cucumis sativus*), and pepper (*Capsicum frutescens*), collected from three major vegetable production zones in Yopougon: Adiopodoumé (Km 17), Niangon Adjamé (Lièvre-Rouge), and Niangon Attié (Attiesso). The sampling period extended from August 2024 to February 2025.

A: Peppers (Capsicum annuum); B: Lettuce (Lactuca sativa); C: Cucumbers (Cucumis sativus); D: Tomatoes (Solanum lycopersicum).All products are collected aseptically at the production sites in BIOHAZARD weighing bags, using sterile, single-use latex gloves

Figure 2 Photographs of vegetables

2.3. Sample Analysis Equipment

2.3.1. Laboratory Equipment

The equipment for pesticide residue detection included: glassware, an electric mixer for grinding samples, an electronic balance for weighing, a shaker for homogenizing extracts, a centrifuge for phase separation, a vacuum pump for filtration, solvent evaporation, and sample concentration/purification, ensuring precise and reliable residue detection. Additional tools included Wattman filter paper, pro-pipettes (100 µL to 1000 µL), vials for extract collection, a micro-syringe for HPLC injection, and an HPLC device for pesticide residue separation and identification.

2.3.2. Reagents and Solvents

The solvents consisted of distilled water, methanol, dichloromethane (DCM), borate buffer, chloroformate chloride (9-fluorenylmethyl), hexane, sodium hydroxide, and hydrochloric acid.

2.4. Site and Vegetable Selection

The studied production zones included Adiopodoumé (Km 17), Niangon Attié (Attiesso), and Niangon Adjamé (Lièvre Rouge), representing the primary sources of fresh vegetable supply for Yopougon and its surroundings. Located in urbanized plains, these areas are bordered by factories and supplied with wastewater and runoff, with solid waste nearby. These sites were chosen for their accessibility and the availability of voluntary producers. Additionally, the Gouro Market in Adjamé, a major trading hub, concentrates wholesale sellers of vegetables, fruits, and other foodstuffs, serving as a strategic distribution point for farmers from Abidjan and inland regions.

2.5. Sample Collection

For sampling, three production zones (Adiopodoumé, Niangon Adjamé, and Niangon Attié) were selected, with three production sites per zone. Within each site, plots managed by producers were chosen for sampling. A total of 1 kg of each vegetable (tomatoes, cucumbers, peppers, lettuce), freshly harvested from each plot, was randomly collected, placed in sterile BIOHAZARD plastic bags (Fisher Scientific), and handled with sterile Synguard latex gloves. All samples were collected between August 2024 and February 2025. Due to varying treatments applied to each vegetable type, three samples per product were taken per site, totaling 36 samples across all zones. The labeled samples were stored in coolers with dry ice for preservation and transported to microbiology and biotechnology laboratories for treatment. Subsequently, they were sent to the National Agricultural Development Support Laboratory (LANADA) for pesticide residue analysis via high-performance liquid chromatography (HPLC).

2.6. Pre-Analysis Treatment

For each treatment, a 100 g portion of each fresh vegetable was accurately weighed using an analytical balance. The treatment methods were implemented as described below, with three replicates per method.

2.6.1. Untreated Control

For each analyzed vegetable, 500 g of fresh samples were weighed without prior treatment. Portions of 100 g were then placed in labeled Stomacher bags for traceability.

2.6.2. Running Water Wash

A total of 500 g of each fresh vegetable sample was washed under running water for 5 minutes. After drying with absorbent paper, the samples were allocated based on treatment plans and collection sites.

2.6.3. Soaking Treatments for Chemical Contamination Reduction

Vegetable samples underwent various soaking treatments to reduce chemical contamination. For the first treatment, a 1% sodium hypochlorite solution was prepared by mixing 250 mL of 8% bleach with 1750 mL of tap water in 5000 mL beakers, totaling 2000 mL. Each 100 g sample was immersed for 5 minutes. For the second treatment, a 1% sodium bicarbonate solution was prepared by dissolving 20 g of sodium bicarbonate in 2000 mL of **ice-cold water**, with samples soaked for 10 minutes. A third combined treatment was performed by mixing 250 mL of 8% bleach with 1750 mL of **ice-cold water**, adding 20 g of sodium bicarbonate, for a total volume of 2000 mL. Samples were immersed in this combined solution for 5 minutes. After each treatment, the vegetables were thoroughly rinsed, drained, and prepared for analysis. Treated samples were stored in coolers with dry ice for transport to LANADA, where extraction analyses were conducted.

These treatments leverage the complementary properties of sodium hypochlorite and sodium bicarbonate, two safe and widely available agents. Sodium bicarbonate, a safe alkaline cleaner, acts against microorganisms and pesticide residues, while sodium hypochlorite, an affordable disinfectant, eliminates a broad spectrum of pathogens due to its strong oxidizing power.

2.7. Pesticide Analysis

2.7.1. Sample Preparation

Fresh vegetable samples (lettuce, tomatoes, cucumbers, peppers) were prepared following a standardized protocol for pesticide quantification. After washing, 100 g of each vegetable were precisely weighed, ground into a homogeneous paste, and stored in sterile containers at low temperatures before chromatographic analysis.

2.7.2. Pesticide Quantification

Pesticide residue analysis in vegetables was conducted according to the **NF EN 12393-3 (December 2013)** standard using HPLC. A 50 g homogenized sample was mixed with 30 mL of distilled water, blended, and centrifuged. The supernatant was filtered through Wattman No. 114 paper and further purified using a C18 column activated with methanol and distilled water. Pesticide residues were eluted with 2 mL of methanol, collected in sterile vials, and injected into the HPLC for detection and quantification. Identification relied on chromatographic peak analysis, while quantification was based on calibration curves from certified standards.

2.7.3. Quality Assurance

Quality criteria were strictly applied to evaluate method performance. The Limit of Quantification (LOQ) was set at 0.009 $mg·kg^{-1}$, varying by pesticide type, while the Limit of Detection (LOD) was 0.017 µg/kg. Residue quantification (mg/kg) was performed via HPLC peak area analysis and calibration curves, ensuring precise, reproducible results compliant with European regulatory standards.

2.7.4. Concentration Quantification

Pesticide detection and quantification by HPLC were based on calibration curves expressed as: A = k·C + b, where A: peak area; k: slope; b: y-intercept (**He et al., 2019**). Critical parameters (temperature, flow rate, mobile phase composition) were rigorously controlled for accuracy (**Khotimah et al., 2020**). Residue confirmation was achieved via HPLC-MS/MS, analyzing mass/charge ratios (*m/z*) for precise identification and quantification, complying with ISO/IEC 17025 standards for reliable regulatory analysis.

2.8. Health Risk Assessment

Health risk assessment for pesticide residues compared measured concentrations in vegetables to MRLs established by regulatory bodies (EU/FAO/Codex). The Hazard Quotient (HQ) was calculated as follows:

$$HQ = \frac{C}{MRL}$$

- **C**: Pesticide residue concentration in the vegetable (mg/kg or ppm).
- **MRL**: Maximum Residue Limit (mg/kg).

If HQ ≥ 1: The risk is deemed concerning (residue exceeds toxicological reference values).

2.8.1. Standards, Acceptable Daily Intake (ADI), and Maximum Residue Limits (MRLs)

Table 1 Quality Standards and Pesticide Residue Limits

Pesticide	ADI (mg/kg bw/day)	MRL - Fresh Vegetables (mg/kg)	References (EU/FAO/Codex)
Métamitron	0.01	0.05	EU Regulation 2023/814
Crimidine	0.0005	0.01	Codex STAN 193-1995
Monuron	0.02	0.1	EU Regulation 2020/856
Monolinuron	0.025	0.2	EU Regulation 2019/1797
Chlortoluron	0.015	0.5	EU Regulation 2021/1902
Terbuthylazine	0.004	0.05	EU Regulation 2022/1434
Métazachlore	0.01	0.3	EU Regulation 2020/1085
Diuron	0.001	0.1	EU Regulation 2023/771
Linuron	0.005	0.2	EU Regulation 2018/832
Prometryne	0.01	0.05	EU Regulation 2021/1099
Isoproturon	0.006	0.1	EU Regulation 2019/1862
Chlorprophame	0.03	0.5	EU Regulation 2022/1015

Métolachlore	0.005	0.05	EU Regulation 2020/1248
Vinclozoline	0.01	0.05	EU Regulation 2018/1480
Parathion-éthyl	0.004	0.02	Codex STAN 197-1995

2.9. Statistical Analysis

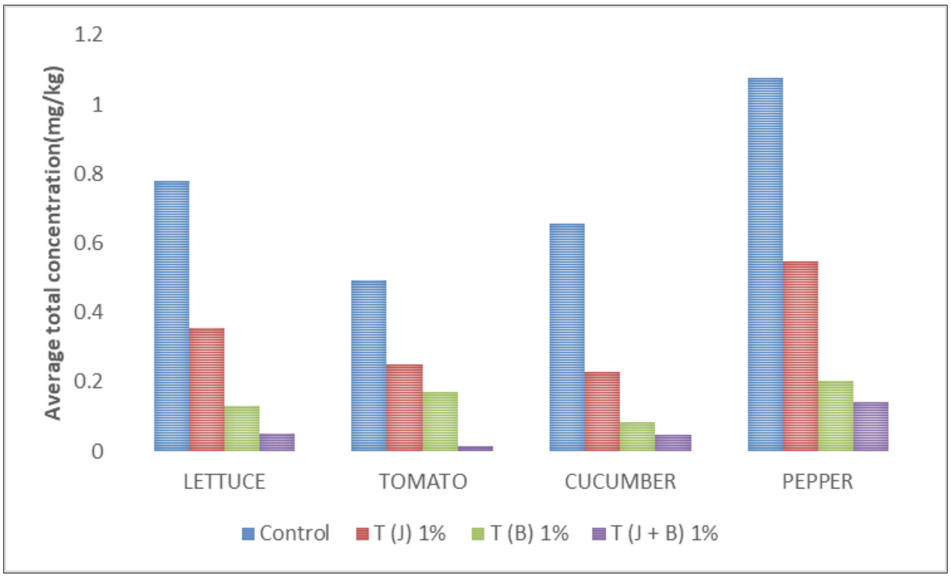
Descriptive statistics (mean, standard deviation) and histograms were generated using Excel (Microsoft Office 2019). For statistical comparisons, XLSTAT (2006 version) was employed, including ANOVA followed by Duncan's post-hoc test (significance threshold: $p < 0.05$).

3. Results and Discussion

The pesticide residue results presented in this study derive from vegetable samples subjected to different treatments, as described in the Materials and Methods section. These treatments were implemented to evaluate the efficacy of decontamination practices in reducing pesticide residues in fresh vegetables.

3.1. Mean Total Concentrations of Active Substances in Different Vegetables

This study highlights the varying efficacy of three vegetable decontamination protocols against pesticide residues. Initial residue concentrations in controls followed this hierarchy: pepper (1.078 mg/kg) > lettuce (0.778 mg/kg) > cucumber (0.656 mg/kg) > tomato (0.492 mg/kg). This diversity reflects species-specific accumulation mechanisms, corroborated by research on pesticide bioaccumulation variations due to anatomical and physiological plant traits (AlSaikhan et al., 2021; Bars et al., 2020). Plants with thinner cuticles (e.g., tomato) showed higher contamination levels, facilitating chemical absorption, while thick-cuticle peppers acted as more effective barriers, requiring tailored decontamination strategies.



T: Treatment; **J**: Bleach; **B**: Sodium bicarbonate; **J+B**: Bleach + sodium bicarbonate

Figure 3 Pesticide residue concentrations in Yopougon vegetables after decontamination

For the 1% sodium hypochlorite (NaClO) treatment (5 min), average residue reduction efficacy ranged between 49.07% and 65.40%, aligning with prior studies (Park et al., 2022). The oxidative mechanism of NaClO is well-documented, but operational parameters must be strictly followed to avoid toxic byproduct formation (AlSaikhan et al., 2021).

The 1% sodium bicarbonate ($NaHCO_3$) treatment (10 min) showed improved efficacy (65.45–87.35%), consistent with alkaline hydrolysis's potential for pesticide degradation (Ramadan et al., 2020). However, prolonged exposure or higher concentrations may compromise vegetable texture (Bars et al., 2020), underscoring the need for adherence to guidelines.

The combined protocol (NaClO 1% + $NaHCO_3$ 1%) achieved exceptional performance, exceeding 90% reduction for most vegetables, validating the synergy between oxidative and alkaline treatments (Chouti et al., 2018). However, this approach risks tissue degradation and byproduct formation, necessitating stringent parameter control for commercial-scale application (Dakuyo et al., 2020).

Anatomically, decontamination efficacy varied with vegetable morphology. Tomatoes, with thinner cuticles, allowed better agent penetration, while thick-cuticle peppers required adapted treatments (El-Mageed et al., 2022). Despite its efficacy, the combined method faces three major constraints: operational control, regulatory compliance for hypochlorite, and economic implications of complex procedures.

3.2. Pesticide Residues in Treated Vegetables

This study detected 17 pesticide molecules from six chemical families in four commonly consumed raw vegetables in Yopougon. Herbicides dominated (70.59%), followed by insecticides (23.53%) and fungicides (5.88%), reflecting intensive agricultural practices (Rimayi et al., 2018). Significant interspecies variations were observed, with elevated concentrations in peppers and lettuce, indicating crop-specific residue selectivity (Mazibuko et al., 2023).

Triazines and urea derivatives were most concerning. Chlortoluron (0.388 mg/kg) is linked to endocrine disruption and liver depression (Abass et al., 2021). Metamitron (0.091 mg/kg) poses potential carcinogenic risks, while diuron (0.271 mg/kg) is associated with renal and thyroid disorders (Banjac et al., 2022). Organophosphates like ethyl-parathion (0.109 mg/kg) exhibit acute neurotoxicity via acetylcholinesterase inhibition (D'Amico et al., 2021). Carbamates and dicarboximide fungicides, with estrogenic properties, raise endocrine disruption concerns (Milićević et al., 2024).

Herbicide predominance underscores excessive chemical reliance, a documented issue in sub-Saharan Africa (Rimayi et al., 2018). This poses multifaceted health risks, from carcinogenicity to neurological impairments (Rives et al., 2020; Goh et al., 2022). As vegetables are typically consumed raw, the absence of thermal treatment exacerbates concerns. The findings urge revised agricultural practices in Yopougon, emphasizing reduced triazine/urea herbicide use and enhanced residue monitoring (Mazibuko et al., 2023). Policy reforms should promote sustainable practices, minimize pesticide impacts, and educate consumers, integrating this study into broader urban African food safety frameworks (Dhagat & Jujjavarapu, 2021).

In conclusion, integrated crop management strategies—including conservation agriculture and alternative pest control—are needed to reduce synthetic pesticide dependence and mitigate human/environmental harm (Manzoor & Pervez, 2022; Mazibuko et al., 2023).

Table 2 Mean Concentrations of Active Substances in Yopougon Vegetables After decontamination

Pesticide		**Lettuce**				**Tomato**				**Cucumber**				**Pepper**			
Famille	**Molécules**	**control**	**J**	**B**	**J+B**	**control**	**J**	**B**	**J+B**	**control**	**J**	**B**	**J+B**	**control**	**J**	**B**	**J+B**
TRIAZINE	Métamitron	0.050 ± 0.002^{b}	0,016 ± 0,001^{d}	0,001 ± 0^{e}	ND	ND	ND	ND	ND	0.088 ± 0.002^{a}	0,029 ± 0,003^{c}	ND	ND	ND	ND	ND	ND
	Crimidine	0.041 ± 0.004^{a}	0,015 ± 0,002^{c}	0,002 ± 0^{d}	ND	ND	ND	ND	ND	0.027 ± 0.003^{b}	0,002 ± 0^{d}	ND	ND	ND	ND	ND	ND
	Métoxuron	0.080 ± 0.005^{a}	0,034 ± 0,003^{c}	0,032 ± 0,002^{c}	0,003± 0,001^{d}	0.030 ± 0.003^{c}	ND	ND	ND	0.070 ± 0.003^{a}	0,046 ± 0,005^{b}	ND	ND	ND	ND	ND	ND
	Monuron	ND	ND	ND	ND	ND	ND	ND	ND	0.299 ± 0.03^{a}	0,025 ± 0,001^{b}	ND	ND	ND	ND	ND	ND
UREA DERIVATIVES	Chlortoluron	0.300 ± 0.03^{a}	0,168 ± 0,01^{c}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.232 ± 0.002^{b}	0,017 ± 0,002^{d}	ND	ND
	Terbuthylazine	0.081 ± 0.008^{a}	0,023 ± 0,001^{b}	0,008 ± 0^{c}	0,006± 0^{c}	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Métazaclor	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	0.337 ± 0.003^{a}	0,133 ± 0,001^{b}	ND	ND
	Diuron	0.072 ± 0.004^{g}	ND	ND	ND	0.257 ± 0.003^{b}	0,15 ± 0,006^{d}	0,122 ± 0,009^{e}	0,015 ± 0.001^{h}	0.217 ± 0.002^{c}	0,112 ± 0,002^{f}	0,09 ± 0^{fg}	0,028 ± 0,001	0.271 ± 0.04^{a}	0,156 ± 0,003^{d}	0,127 ± 0,003^{e}	0,051± 0,001^{gh}
	Linuron	ND	ND	ND	ND	0.143 ± 0.005^{a}	0,082 ± 0,002^{c}	0,023 ± 0^{g}	ND	0.077 ± 0.004^{d}	0,023 ± 0,001^{g}	0,008 ± 0^{i}	ND	0,103± 0.012^{b}	0,064 ± 0,001^{e}	0,037 ± 0,001^{f}	0,014±0,002^{h}
	Prometryn	ND	ND	ND	ND	0.042 ± 0.005^{b}	0,015 ± 0,001^{d}	ND	ND	0.025 ± 0.001^{c}	0,005 ± 0^{e}	ND	ND	0.067 ± 0.003^{a}	0,026 ±0,002^{c}	0,014 ± 0,002^{d}	0,008±0,002^{de}

	Isoproturon	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.22 ± 0.002^{a}	0,17 ± 0,001^{b}	ND	ND
CARBOMATE	Chlorpropham	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.052 ± 0.002^{a}	0,019 ± 0,002^{b}	ND	ND
ORGANOPHOSPHORE	Vinclozolin	ND	ND	ND	ND	ND	ND	ND	ND	0.017 ± 0.003^{a}	0,008± 0^{b}	ND	ND	ND	ND	ND	ND
	Parathion-éthyl	0.109± 0.002^{a}	0,08 ± 0,004^{b}	0,068 ± 0,001^{bc}	0,013± 0,001^{e}	ND	ND	ND	ND	ND	ND	ND	ND	0,045± 0,003^{d}	0,013± 0,002^{e}	ND	ND

3.3. Health Risk Assessment

Table 3 highlights major concerns regarding food safety linked to the consumption of vegetables contaminated with pesticide residues, frequently exceeding maximum allowable limits (MRLs). The analysis of residual concentrations shows that several pesticides significantly exceed MRLs, indicating a notable public health risk. In particular, ethyl-parathion displays an alarming hazard quotient (HQ) (5.45 in untreated lettuce, 272 times the MRL of 0.02 mg/kg), confirming recent observations on the persistence of organophosphates in leafy vegetables (Hua & Liu, 2024). Substituted ureas (diuron, linuron) also show systemic exceedances, with HQs exceeding 2.5 for diuron in three different crops, corroborating EFSA conclusions on the accumulation of these compounds (Ssemugabo et al., 2023).

The evaluation of treatment methods reveals marked variations in the effectiveness of the approaches employed. The combination of sodium hypochlorite and sodium bicarbonate (J+B method) stands out for its ability to reduce crimidine levels from 0.038 to 0.002 mg/kg, representing 94.7% elimination. For terbuthylazine HQs, an HQ of 1.92 compared to an MRL of 0.05 mg/kg raises food safety concerns (Park et al., 2021). For acute risks, diuron consumption in peppers, with concentrations reaching 0.271 mg/kg, could indicate significant risks, echoing observations documented by (Ssemugabo et al., 2023). Although the J+B method represents an optimal solution (85–95% elimination), its application requires strict control of operational parameters (immersion time ≤7 minutes, concentration at 1%, thorough rinsing) to preserve the organoleptic and nutritional qualities of vegetables while minimizing risks of digestive irritation and chemical residue-related hypersensitivity (Thakur et al., 2022). This balanced approach between decontamination efficacy and food safety is essential for optimal management of health risks associated with pesticide residues.

Table 3 Comparative Table of Residual Pesticide Concentrations and Hazard Quotients (HQ) in Market Vegetables

Pesticide Molecule	**Produit**	**Concentration (mg/kg)**				**LMR (mg/kg)**	$\mathbf{HQ = \frac{C}{MRL}}$			
		T	**J**	**B**	**J+B**		**T**	**J**	**B**	**J+B**
Métamitron	Lettuce	0,067	0,019	0,003	ND	0,05	1,34	0,38	0,06	ND
	Tomato	0.044	0,014	ND	ND		0,88	0,28	ND	ND
	Cucumber	0.091	0,034	0,002	ND		1,82	0,68	0,06	ND
	Pepper	0.033	0,011	ND	ND		0,66	0,22	ND	ND
Crimidine	Lettuce	0,038	0,011	0,002	ND	0,01	3,8	1,1	0,2	ND
	Tomato	0.006	ND	ND	ND		0,6	ND	ND	ND
	Cucumber	0.019	0,006	ND	ND		1,9	0,6	ND	ND
Métoxuron	Lettuce	0,076	0,038	0,012	0,002	0,05	1,52	0,76	0,24	0,04
	Cucumber	0,099	0,049	0,019	ND		1,98	0,98	0,38	ND
Monuron	Lettuce	0.018	0.008	ND	ND	0,1	0,18	0,08	ND	ND
	Cucumber	0.099	0,035	ND	ND		0,99	0,35	ND	ND
	Pepper	0.017	0.008	ND	ND		0,17	0,08	ND	ND
Monolinuron	Lettuce	0,016	0,007	0,002	ND	0,2	0,08	0,035	0,01	ND
	Cucumber	0,012	0,005	ND	ND		0,06	0,025	ND	ND
Métazaclor	Pepper	0,17	0,13	ND	ND	0,3	0,567	0,433	ND	ND
Chlortoluron	Lettuce	0.388	0,188	0,006	ND	0,5	0,776	0,376	0,012	ND
	Pepper	0.100	0,021	ND	ND		0,2	0,042	ND	ND
Terbuthylazine	Lettuce	0.096	0,026	0,009	ND	0,05	1,92	0,52	0,18	ND
Parathion-éthyl	Lettuce	0,109	0,08	0,068	0,013	0,02	5,45	4	3,4	0,65
	Pepper	0,045	0,013	ND	ND		2,25	0,65	ND	ND

Diuron	Tomato	0,257	0,15	0,122	0,015	0.1	2,57	1,5	1,22	0,15
	Cucumber	0,217	0,112	0,090	0,028		2,17	1,12	0,90	0,28
	Pepper	0,271	0,156	0,127	0,051		2,71	1,56	1,27	0,51
Linuron	Tomato	0,143	0,082	0,023	ND	0.2	0,715	0,41	0,115	ND
	Cucumber	0,077	0,023	0,008	ND		0,385	0,115	0,04	ND
	Pepper	0,103	0,064	0,037	0,014		0,515	0,32	0,185	0,07
Prometryn	Tomato	0,042	0,015	ND	ND	0,05	0,84	0,3	ND	ND
	Cucumber	0,025	0,005	ND	ND		0,5	0,1	ND	ND
	Pepper	0,067	0,026	0,014	0,008		1,34	0,52	0,28	0,16
Isoproturon	Pepper	0,22	0,17	ND	ND	0,1	2,2	1,7	ND	ND
Chlorpropham	Pepper	0,052	0,019	ND	ND	0,5	0,104	0,038	ND	ND
Vinclozolin	Cucumber	0,017	0,008	ND	ND	0,05	0,34	0,16	ND	ND

(T: Control; J: Sodium hypochlorite; B: Sodium bicarbonate; J+B: Sodium hypochlorite + sodium bicarbonate; ND: Not detected ; C: Pesticide residue concentration in the vegetable; MRL: Maximum Residue Limit; HQ: Hazard Quotient)

4. Conclusion

This study reveals a concerning contamination of Yopougon vegetables with pesticide residues, frequently exceeding maximum allowable limits (MRLs). Among the tested washing methods, the combination of sodium hypochlorite and sodium bicarbonate in ice-cold water proved most effective, achieving residue reductions exceeding 90% for most analyzed vegetables. However, the persistence of certain pesticides, such as ethyl-parathion and diuron, remains alarming due to their neurotoxic, carcinogenic, and endocrine-disrupting effects.

In conclusion, this study underscores the urgency for intervention to protect public health while encouraging a transition toward sustainable agricultural practices. Combining preventive measures (reducing pesticide use) and curative measures (optimized washing methods) presents a promising approach to enhance the food safety of vegetables in Yopougon and similar contexts.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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