JOURNAL OF FOOD QUALITY & HAZARDS CONTROL
SHAHID SADOUGHI UNIVERSITY OF MEDICAL SCIENCES & HEALTH SERVICES

**Journal of Food Quality and Hazards Control 12 (2025) 150-159**

# Pesticide Residues in Tomato, Eggplant, and Cabbage Grown in the Western Province of Rwanda

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## HIGHLIGHTS

- This study analyzed pesticide residue of the most commonly used pesticides in tomato, cabbage, and eggplant from the Western Province of Rwanda.
- The predominant insecticides detected were cypermethrin (40.75%), metalaxyl (30.98%) profenofos, and deltamethrin (26.24%).
- Findings indicated that pesticide residues contaminated 30, 36.67, and 23.33% of the sampled tomato, cabbage, and eggplant, respectively.
- Public awareness regarding pesticide use and management should be raised urgently to ensure consumer safety.

***Article type***
Original article

***Keywords***
Pesticide Residues
Rwanda
Vegetables

***Article history***
Received: 13 Dec 2024
Revised: 17 Mar 2025
Accepted: 7 Jun 2025

***Abbreviations***
ADI=Acceptable Daily Intake
ARfD=Acute Reference Dose
HPLC=High Performance Liquid Chromatography
HQ=Hazard Quotient
HRI=Health Risk Index
LOD=Limit of Detection
MRLs=Maximum Residue Limits
WHO=World Health Organization

## ABSTRACT

**Background:** Pesticide use in agriculture enhances crop production but poses risks to public health and the environment, necessitating rigorous food safety monitoring. Hence, this study aimed at assessing the levels of pesticide residues in tomato, eggplant, and cabbage grown in the eastern province of Rwanda.

**Methods:** A survey involving 300 farmers and 30 agrodealers was conducted in Rwanda's Western Province to identify commonly used pesticides and measure their residues in cabbage, tomato, and eggplant from Rusizi and Nyamasheke. Residue analysis of metalaxyl, cypermethrin, abamectin, deltamethrin, and profenofos was performed using High Performance Liquid Chromatography. Consumer health risks were assessed via acute Health Risk Index and chronic Hazard Quotient (HQ) values. Data were analyzed using descriptive statistics in IBM SPSS Statistics 29.0.2.0 and Microsoft Excel 2016.

**Results:** Fungicides (60%), insecticides (33%), herbicides (3%), and acaricides (2%) were applied, with metalaxyl (24%) and chlorothalonil (13%) as the predominant fungicides. Insecticide use was led by cypermethrin (40.75%), metalaxyl (30.98%), profenofos, and deltamethrin (26.24%). Pesticide residues contaminated 30%, 36.67%, and 23.33% of tomato, cabbage, and eggplant samples, respectively. Mean residue levels of metalaxyl in tomato (0.793 ppm) and cabbage (1.089 ppm), and deltamethrin in eggplant (0.475 ppm) and cabbage (0.550 ppm) exceeded Food and Agriculture Organization and Codex Alimentarius Maximum Residue Limits. Acute Health Risk Index for all pesticides were below 100% of the Acute Reference Dose, indicating minimal acute risk. HQ were below one for all pesticides except cyhalothrin (HQ=1.313) and abamectin (HQ=2.15) in eggplant.

**Conclusion:** Based on these findings, there is an urgent need for improving pesticide management and raising public awareness on the use of pesticides among farmers, pesticides sellers, and consumers.



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**To cite:** Ntamuturanyi J.B., Nkurunziza E., Rutikanga A., Muhizi T., Umereweneza D. (2025). Pesticide residues in tomato, eggplant, and cabbage grown in the western province of Rwanda. *Journal of Food Quality and Hazards Control*. 12: 150-159.

**DOI:** 10.18502/jfqhc.12.2.18865 Journal website: http://jfqhc.ssu.ac.ir

## Introduction

Rwanda, like most developing African countries, is experiencing an alarming population increase, with an annual population growth rate of 2.3%, the population density of Rwanda in 2023 was 525 people per $km^2$ (Gatwaza and Wang, 2023). Sustainable agriculture constitutes one of the economic priority pillars for achieving vision 2050 (Perez-Guzman et al., 2023). However, the sector is facing various challenges. The population increase cannot be sustainable and beneficial without a parallel increase in food production leading to overexploitation of available land accompanied by agricultural malpractices (Mosnier et al., 2023). Due to the rapid urbanization, the arable soil for agriculture in Rwanda decreases at a rapid rate leading to the declining of food production (Li et al., 2021). To overcome these challenges, there is a need to increase soil productivity by using agricultural inputs like fertilizers to increase harvest on surface area and pesticides to manage pests and thus crop diseases (Ndayambaje et al., 2019).

The agricultural application of pesticides contributes to food security. Various pesticide application methods exist, including spraying over crops and applying them in the soil, which result in direct release into the environment (Houbraken et al., 2017). Therefore, the continued use of pesticides and the increase of residue accumulation in some vegetables constitute a threat to the consumers' health and safety. Pesticide residues refer to the pesticide that remains with food after application (Bai et al., 2006). The use of pesticides in Rwanda is continuously increasing (Silvestri et al., 2019) and this increase needs a constant monitoring and evaluation for environmental protection and reducing health risk effect (Houbraken et al., 2017; Umubyeyi and Rukazambuga, 2016).

The analysis of pesticide residues in foodstuff is among the priorities highlighted by the World Health Organization (WHO) due to not only acute poisonings but also long-term effects of high levels of pesticide residues in foods on the consumers' health (Ma et al., 2022). The short-term poisonings caused by pesticides including allergies, headache, and dizziness. Moreover, long-term exposure to higher concentrations of pesticide residues may be responsible for various chronic adverse health effects such as obesity, diabetes, asthma, and cancers (Kafle et al., 2021; Mostafalou and Abdollahi, 2017). The acute Health risk (aHI) to a consumer is established as a ratio between the Estimated Short-Term Intake (ESTI) and the Acute Reference Dose (ARfD) of a pesticide. Similarly, the chronic health hazard is measured as a quotient of the Estimated Daily Intake (EDI) of a pesticide to the Acceptable Daily Intake (ADI) of the pesticide (Nisha et al., 2021).

To ensure the food safety, numerous regulations such as codex directives and European Commission standards have established Maximum Residue Limits (MRLs) for pesticides in foodstuffs (Algharibeh and Alfararjeh, 2019). The aim of the present study was to identify the most used pesticides and determine their residue levels in cabbage, tomato, and eggplant from Rusizi and Nyamasheke in Western Province of Rwanda.

## Materials and methods

*Data collection by survey*

To identify the most common pesticides in the Western Province of Rwanda, a survey was conducted using a questionnaire. This questionnaire consisted of three sections: the first part was composed of questions about sociodemographic status of the informants. Introductory information was collected such as age, level of education, and marital status. The second section was aimed at gathering information on pesticide application including the applied pesticide type and quantity, pesticide mode, and frequency of application. The last section was about the safety of pesticide application. This part was targeting the level of training regarding pesticide application methods, availability of personal protective equipment, and knowledge about the health effects associated with inappropriate pesticide application.

*Sample collection*

A total of 90 samples were collected from Tyazo and Bushenge markets in Nyamasheke district and Bugarama valley market in Rusizi district from November 2022 to February 2023. They included 30 samples of each vegetable type that is tomato, cabbage, and eggplant.

Samples were collected from each site on three different days; one kg of each vegetable type of interest was packed each day. During sampling gloves were used and changed every time before collecting next sample. The dust was removed without washing and then samples were placed into ice-containing polyethylene bag. They were labeled, packed separately, transported to the laboratory, and kept in the freezer at -20 °C until further analysis carried out within one week.

*Sample preparation by extraction*

After washing with distilled water, samples made entirely of vegetables were cut into pieces and then ground using mortar and pestle. Each sample was homogenized prior to extraction of pesticide residues. The extraction was done using the method known as Quick Easy Cheap Effective Rugged, and Safe (QuEChERS) multi-residue analytical approach as described in Figure 2 (Payá et al., 2007). This technique involved liquid partitioning using acetonitrile and purifying the extract using dispersive solid-phase extraction and has been proven to be efficient for pesticide residues (Figure 1) (Rejczak and Tuzimski, 2015). After extraction, the sample was cleaned up by the use of dispersive Solid Phase Extraction (dSPE) (Payá et al., 2007). Finally, the cleaned supernatant was transferred to an autosampler vial for analysis by High Performance Liquid Chromatography (HPLC; Shimadzu, Japan).

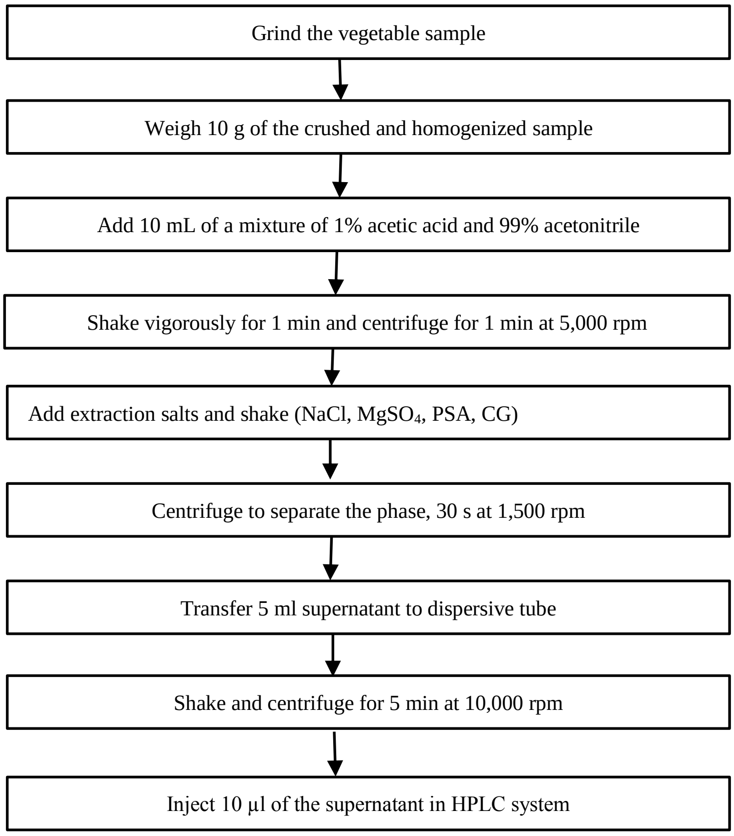

**Figure 1:** Flow chart for extraction of pesticide residues
HPLC=High Performance Liquid Chromatography

*HPLC instrument conditions*

HPLC system was made up of an SPD-20A Shimadzu UV/VIS detector (Shimadzu, Japan), a CTO-10AS VP Shimadzu column oven, a CBM-20A Communication bus module, a DGU-20 A5 Degasser, an LC-20AD Liquid chromatography pump, an SIL-20A Auto sampler and a Nucleosol 100-5-C18 250×3.2 mm column (Macherey–Nagel, Düren, Germany). A mixture of acetonitrile and water (3:2) was used as mobile phase for removal of any impurity, bubbles, and dissolved oxygen. Prior to injection, the acetonitrile-water mixture was first filtered through a 0.45 µm filter paper then sonicated for 15 min. The injected sample volume was 10 µl with the flow rate of one ml per min at 35 ℃.

*Quality control of analysis method*

The system performance was checked as recommended by European Commission regarding the measurement of recoveries, precision, Limit of Detection (LOD), Limit of Quantification (LOQ), and linearity. These parameters were evaluated by spiking samples with two different concentrations in eggplant, tomato, and cabbage. The reference sample was spiked at two levels (0.5 and 0.1 ppm) of the targeted pesticide and passed through the same procedure as the sample. The range of LOD was between 0.009 and 0.059 ppb, with alpha-cypermethrin having the lowest LOD while profenofos had the highest ranging between 0.032 and 0.195 ppb. The analyzed pesticide residues namely methalaxyl, chlorothalonil, alpha-cypermethrin, profenofos, deltamethrin, abamectin, and cyhalothrin showed strong linearity, with correlation coefficient ranging from 0.999 to 1. This suggested that the method was accurate and rapid to determine the residue levels of the target pesticides in tomato, eggplant, and cabbage.

*Health Risk Index (HRI)*

The extent of the effects of consuming pesticide-contaminated food is referred to as pesticide health risk assessment. The health risks of acute and chronic exposure to the pesticide have been investigated. The HRI is measured as follows (Nisha et al., 2021):

$$HRI = \frac{ESTI}{ARfD} \quad (1)$$

$$ESTI = hRL \times \frac{FC}{BW} \quad (2)$$

Where ARfD: Acute Reference Dose of a particular pesticide (mg/kg/day); ESTI: Estimated Short-Term Intake of a pesticide (mg/kg/day); hRL: highest Residue Level (mg/kg/day); FC: Food Consumption; BW: body weight (kg).

In short-term, if the value of ARfD is higher than ESTI, the consumption of the food containing pesticide residues is not harmful to the exposed consumer.

The chronic health risk has been calculated from Hazard Quotient (HQ) (Nisha et al., 2021):

$$HQ = \frac{EDI}{ADI} \quad (3)$$

$$EDI = mRL \times \frac{FC}{BW} \quad (4)$$

Where EDI: Estimated Daily Intake of a pesticide residue (mg/kg/day); ADI: Acceptable Daily Intake of the pesticide (mg/kg/day); mRL: mean Residue Level.

The values of HQ indicate the effects of the pesticide to the exposed consumer. If HQ is less than one, the harmful effect of the pesticide to the consumer's health is minimal; however, if it is equal to or greater than one, the consumption of the pesticide-contaminated food is no longer safe. The values of ARfD and ADI (mg/kg/day) of a person (60 kg adult and 10 kg children) for cypermethrin, lambda-cyhalothrin, and other pesticides were obtained from literature (Nisha et al., 2021). In Rwanda, the fruit intake is estimated at 14.8 kg/person/year, the number of consumed fruits is higher in cities than in the rural area; while consumption of vegetables is approximated to 46.2 kg/person/year (Bakker et al., 2020).

*Data analysis*

The data were analyzed by descriptive statistics, which permitted the determination of calibration curve, average concentrations of pesticide residues, and standard deviation. IBM SPSS Statistics 29.0.2.0 and Microsoft Excel 2016 software packages were used for this statistical analysis. For each analysis, three replications were performed and the results were presented as Mean±Standard Deviation. One-way analysis of variance (ANOVA) was used to perform statistical analysis of the collected data.

## Results and discussions

*Most commonly used pesticides reported by farmers*

The farmers were interviewed about how they used pesticides while growing different vegetables and crops such as tomato, maize, beans, cabbage, eggplant, Irish potatoes, oranges, and other crops. The results showed that fungicides, insecticides, herbicides, and acaricides were applied at 60, 33, 3, and 2%, respectively. Metalaxyl (24%) and chlorothalonil (13%) were the most applied fungicides in this region of Rwanda. Whereas, insecticides were dominated by cypermethrin (40.75%), profenofos and deltamethrin (26.24%), abamectin (6.11%), and metalaxyl (30.98%) and cyhalothrin (2.5%). These results aligned with the findings of previous study carried out in India by Kaur and Singh (2021). As insecticide, cypermethrin was among the most commonly used pesticides in agriculture as well as in household sanitation (Kaur and Singh, 2021). Fortunately, cypermethrin has been classified by the WHO as a slightly hazardous type II pesticide ( World Health Organization and International Programme on Chemical Safety, 2010).

Collected data also indicated that 95% of the interviewed farmers applied these chemicals using different unconventional ways, increasing the risk of intoxication and environmental pollution. Ninety-six percent of these interviewed farmers had not received any training on pesticide use, and 93.4% handled the chemicals without any protective equipment. Consequently, many applied mixtures with compositions differing from manufacturer recommendations, leading to poor agrochemical management. The outcomes of a similar survey on the use of pesticide, conducted in Ethiopia by Negatu et al. (2016), also highlighted the scarcity of training on the use of pesticides for farmers. This lack of appropriate training has led to improper handling, inadequate mixing of pesticides, and poor personal protection, resulting in farmer self-intoxication and environmental pollution. Consequently, crops grown under such conditions pose health risks to consumers after harvest (Negatu et al., 2016).

*Pesticide residues in analyzed vegetables*

Out of 30 analyzed samples of tomato only nine (30%) samples presented pesticide residues and 21 samples (70%) contained no detectable values of them. Five pesticides, namely metalaxyl, chlorothalonil, alpha-cypermethrin, cyhalothrin, and profenofos were detected in tomato samples. The most detected pesticide in tomato samples was metalaxyl, detected in four samples (13.33%), the second one was chlorothalonil detected in two (6.66%); alpha-cypermethrin, cyhalothrin, and profenofos were detected in only a single sample (3.33%). Abamectin and deltamethrin pesticide residues were not detected in any of the samples. Figure 2 shows the mean values of pesticides detected in tomato samples.

Two pesticides (metalaxyl, chlorothalonil) were detected at the simultaneously in two samples. In addition, metalaxy and profenofos were detected together in one sample. Out of nine contaminated samples, eight samples (88.88%) were collected from Bugarama market and one was picked from Bushenge market. Metalaxyl was detected at the highest concentration of pesticide residue in tomato T3 (1.793 ppm) sample collected from Bugarama market. The presence of these pesticide residues in analyzed vegetables resulted from the use of these chemicals by farmers for pests control in their efforts to increase crop production. The samples from Bugarama displayed the higher amount of pesticide residues due to the excessive use of pesticides. The warm and humid environmental conditions in the area favor the growth of various pests; therefore, farmers are tempted to use higher amounts of pesticides. Unfortunately, farmers do not respect proper pesticide spraying practices, labeling instructions, or the required intervals between spraying and harvesting.

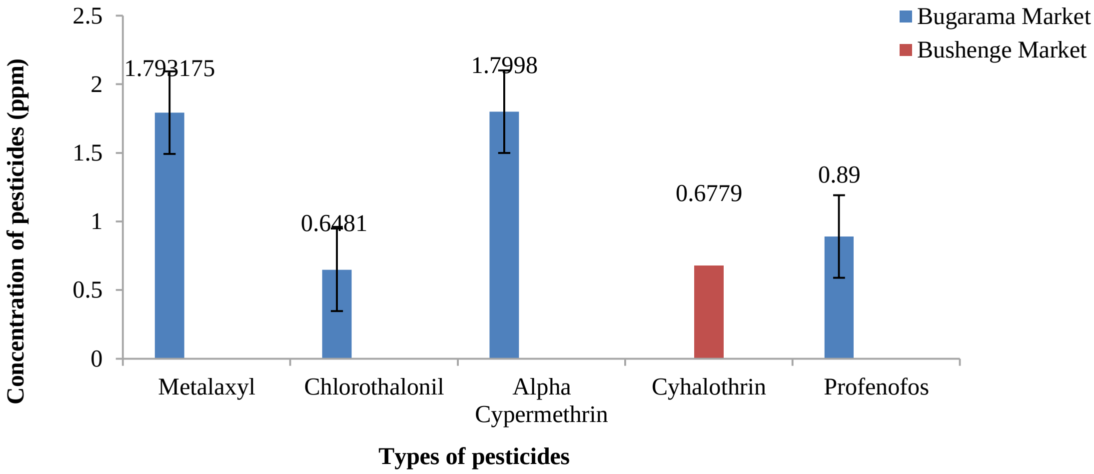


**Figure 2:** Mean of pesticide residues in tomato from three markets (n=30)

Two pesticides (metalaxyl and abamectin) were detected simultaneously in one sample from Bugarama market. Furthermore, alpha-cypermethrin and abamectin were detected simultaneously in one sample collected from Bugarama valley. The presence of pesticide residues was detected in all market samples. Figure 3 presents the mean pesticide residues in cabbage samples from the three markets. Abamectin pesticide residue was detected at a high value in the cabbage (1.684 ppm) sample collected from Bugarama market. The second-highest value was also an abamectin (1.620 ppm) sample from Bugarama market. Bugarama market samples indicated the presence of three pesticides (metalaxyl, alpha-cypermethrin, and abamectin) in cabbage samples. Whereas, Bushenge market's cabbage samples indicated the presence of four pesticide residues (metalaxyl, deltamethrin, alpha-cypermethrin, and abamectin), and Tyazo market's cabbage samples indicated the presence of two pesticide residues (chlorothalonil and deltamethrin).

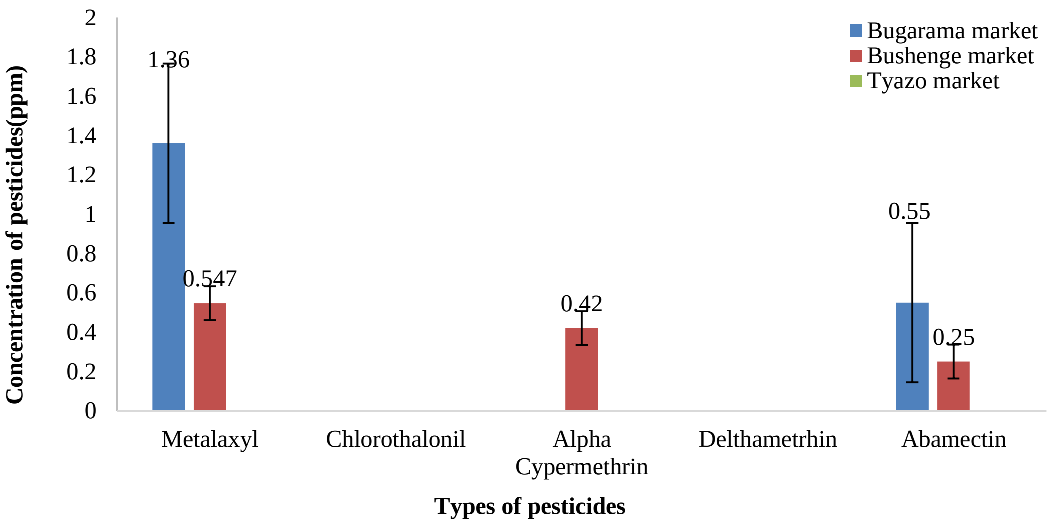


**Figure 3:** Mean pesticide residues in cabbage from three markets (n=30)

Figure 4 shows mean values of the analyzed eggplant samples in the study. Among 30 samples, six presented pesticide residues (20%) and 24 did not (80%). Five pesticides namely metalaxyl, alpha-cypermethrin, deltamethrin, cyhalothrin, and abamectin; chlorothalonil, and profenofos were not detected in eggplant samples. Metalaxyl and alpha-cypermethrin were detected at simultaneously in one sample, S4, collected from Bugarama valley. Alpha-cypermethrin was detected in two samples, S3 and S4, from Bugarama market. The highest pesticide residue detected was cyhalothrin at 1.97 ppm in a sample collected from Tyazo market, while the lowest residue was alpha-cypermetrin at 0.27 ppm from Bugarama market's sample.

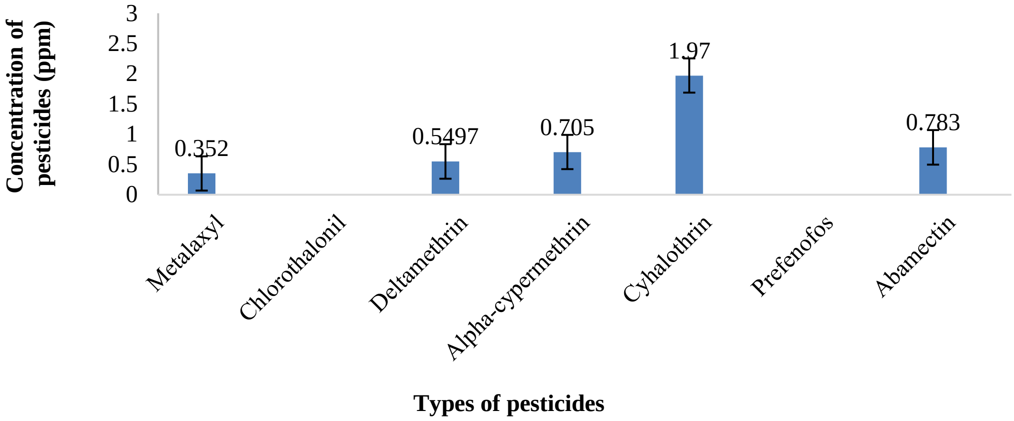


**Figure 4:** Mean pesticide residues in eggplant (n=30)

Pesticide residues were detected in three vegetable samples at different concentrations as shown in Figure 5. Eggplant exhibited the highest pesticide residue with 1.97 ppm of cyhalothrin, followed by tomato with 1.789 ppm of alpha-cypermethrin, and cabbage with 1.652 ppm of abamectin. In this study, the mean values of pesticide residues, such as metalaxyl in tomato (0.79315 ppm) and cabbage (1.089 ppm), and deltamethrin in eggplant (0.4754 ppm) and cabbage (0.5497 ppm), were higher than the MRLs indicated by International food standards such as defined by Food and Agriculture Organization (FAO) and codex Alimentarius (Table 1) (Kuchheuser and Birringer, 2022).

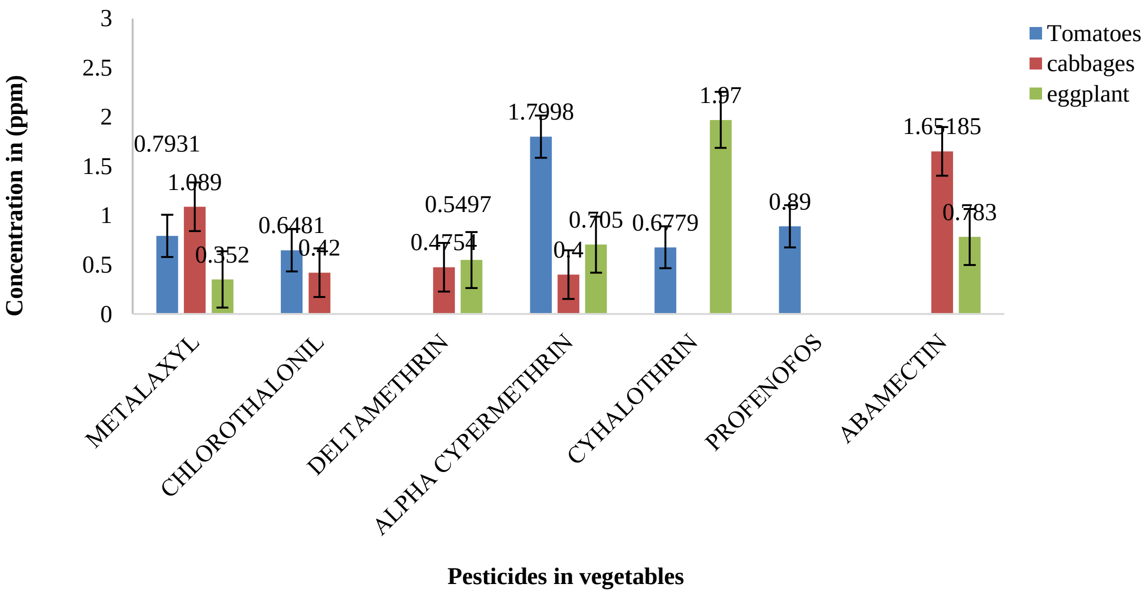


**Figure 5:** Mean pesticide residues in analyzed vegetables (n=90)

**Table 1:** Comparison Of Maximum Residue Limits (MRLs) with the findings of this study (*p*<0.05 for statistical significance)

| Pesticides | MRLs/ADI (mg/kg bw /Day) (FAO/WHO) | | | Average of pesticide residues (Present study) | | |
|---|---|---|---|---|---|---|
| | Tomato | Eggplant | Cabbage | Tomato | Eggplant | Cabbage |
| Metalaxyl | 0.50 | 0.50 | 0.50 | 0.79315±0.13 | 0.352±0.05 | 1.089±0.39 |
| Chlorothalonil | 5.00 | 0.01 | 0.01 | 0.6481±0.36 | - | 0.42±0.05 |
| Deltamethrin | 0.30 | 0.20 | 0.20 | - | 0.5497±0.05 | 0.4754±0.23 |
| Alpha-cypermethrin | 0.20 | 0.03 | 0.03 | 1.7998±0.05 | 0.705±0.43 | 0.4±0.15 |
| Cyhalothrin | 0.50 | 0.20 | 0.20 | 0.6779±0.05 | 1.97±0.05 | - |
| Profenofos | 0.03 | 0.07 | 0.03 | 0.89±0.05 | - | - |
| Abamectin | 0.05 | 0.05 | 0.05 | - | 0.783±0.05 | 1.65185±0.032 |

(-): Below the limit of detection
ADI=Daily Intake of the pesticide; FAO=Food and Agriculture Organization; WHO=World Health Organization

The presented results corroborate previously reported data on the higher concentration cypermethrin in tomatoes grown in different part of the world. Khak et al. (2016) reported that the cypermethrin residue level was higher than the MRLs in 2.8% of the tomato samples harvested from Bushehr Province Farms, Iran (Khak et al., 2016). In Bangladesh, Ahmed et al. (2021) reported that the cypermethrin residues were above the MRLs of the European Union from zero to three days after spray and these were 2.982, 1.726, 0.967, and 0.695 mg/kg with respect to days after spray (Ahmed et al., 2021). In Cameroun, a study conducted by Sepkoutie et al. (2021) disclosed than cypermethrin residues above the MRLs were found in 92.30% of all cypermethrin-contaminated samples (Sopkoutie et al., 2021). However, the data reported by Chavarri et al. (2004) of a research piece of work performed in Spain, revealed that the residual cypermethrin in tomato were below the MRLs of the European Union (Chavarri et al., 2004). Moreover, reported findings from Tanzania showed values of cypermethrin residues below the codex MRLs (Bilaro et al., 2022).

Cyhalothrin exhibited residue level above the FAO-MRLs in tomato and eggplants. This is consistent with the results of the study conducted in Henan Province, China by Ma et al. (2022), which revealed that cyhalothrin and cypermethrin residues were higher especially in urban regions (Ma et al., 2022). Cyhalothrin residues was also among the most detected pesticides in Egypt (Abdelkader et al., 2021). This higher residue level of cyhalothrin observed in different regions of the globe may be due to the chemical similarity of cyhalothrin with natural pyrethrins, which is also associated with its versatility in agriculture applications, efficiency, and low toxicity (Kumar et al., 2007).

*Health risks from pesticide residues*

The effect of exposure to the analyzed pesticides was estimated by using an average body weight of 60 kg and 46.2 kg/year of vegetable consumption (Bakker et al., 2020). The values of ARfD and ADI used to evaluate aHI to a consumer and HQ were obtained from Biopesticides database of the University of Hertfordshire (University of Hertfordshire, 2025).

The consumer health risk was assessed for the analyzed pesticide residues from tomato, eggplant, and cabbage based aHI and HQ values. The calculated values of aHI and HQ are presented in Table 2. None of the calculated aHI values exceeded 100% of the ARfD, suggesting a minimal aHI from consuming vegetables contaminated with the pesticides.

The chronic health risk was evaluated with respect to the HQ values displayed in Table 2. None of the calculated HQ values exceeded the acceptable limit (HQ<1) in all vegetables except cyhalothrin (HQ=1.313) and abamectin (HQ=2.15) in eggplant. These values suggest that the prolonged consumption of the analyzed eggplant might present potential chronic health risks, as they exceeded the tolerable limit.

Long-term exposure to high levels of cyhalothrin have been associated with adverse toxicological effects on health such as inflammation, developmental toxicity, and endocrinal disruption in vertebrates (Sakr and Rashad, 2023). In addition, previous studies have shown that long-standing intakes of abamectin could induce multiple toxic effects including increased level of Reactive Oxygen Species (ROS), DNA double-strand breaks, and apoptosis (Liang et al., 2019). Excessive ROS in the body may cause oxidative stress, which in turn can lead to carcinogenesis, atherosclerosis, diabetes, neurodegeneration, and aging (Ray et al., 2012).

**Table 2:** Health risks from pesticide residues

| Pesticide | Short term | | | Long term | | |
|---|---|---|---|---|---|---|
| | ARfD (mg/kgbw/day) | ESTI (mg/kg/day) | HRI (%) | EDI (mg/kg/day) | ADI (mg/kg/day) | HQ (%) |
| **Tomato** | | | | | | |
| Metalaxyl | 0.5 | $6.49\times10^{-5}$ | 0.013 | $2.64\times10^{-5}$ | 0.08 | 0.099 |
| Chlorothalonil | 0.05 | $3.35\times10^{-5}$ | 0.067 | $2.16\times10^{-5}$ | 0.015 | 0.144 |
| Cypermethrin | 0.20 | $6.92\times10^{-5}$ | 0.035 | $6\times10^{-5}$ | 0.05 | 0.112 |
| Cyhalothrin | 0.01 | $3.28\times10^{-5}$ | 0.328 | $2.26\times10^{-5}$ | 0.005 | 0.452 |
| Profenofos | 1.0 | $3.90\times10^{-5}$ | 0.004 | $2.97\times10^{-5}$ | 0.003 | 0.100 |
| **Eggplant** | | | | | | |
| Metalaxyl | 0.5 | $1.63\times10^{-5}$ | 0.003 | $1.17\times10^{-5}$ | 0.08 | 0.044 |
| Deltamethrin | 0.025 | $2.17\times10^{-5}$ | 0.087 | $1.58\times10^{-5}$ | 0.01 | 0.158 |
| Cypermethrin | 0.20 | $3.87\times10^{-5}$ | 0.019 | $2.35\times10^{-5}$ | 0.05 | 0.047 |
| Cyhalothrin | 0.01 | $9.73\times10^{-5}$ | 0.973 | $6.57\times10^{-5}$ | 0.005 | 1.313 |
| Abamectin | 0.0012 | $3.87\times10^{-5}$ | 3.222 | $2{,}61\times10^{-5}$ | 0.0012 | 2.175 |
| **Cabbage** | | | | | | |
| Metalaxyl | 0.5 | $5.60\times10^{-5}$ | 0.011 | $3.63\times10^{-5}$ | 0.08 | 0.136 |
| Chlorothalonil | 0.05 | $1.97\times10^{-5}$ | 0.039 | $1.40\times10^{-5}$ | 0.015 | 0.093 |
| Deltamethrin | 0.025 | $2.37\times10^{-5}$ | 0.095 | $1.83\times10^{-5}$ | 0.01 | 0.183 |
| Cypermethrin | 0.20 | $2.27\times10^{-5}$ | 0.012 | $1.33\times10^{-5}$ | 0.05 | 0.027 |
| Abamectin | 0.0012 | $7.95\times10^{-5}$ | 6.628 | $5.51\times10^{-5}$ | 0.0012 | 0.138 |

ADI=Acceptable Daily Intake of the pesticide; ARfD=Acute Reference Dose; EDI=Estimated Daily Intake; ESTI=Estimated Short-Term Intake; HQ=Hazard Quotient; HRI=Health Risk Index

## Conclusion

This study focused on assessing the use of pesticides in the Rusizi and Nyamasheke districts of Rwanda's Western Province, the ways in which farmers used pesticides had potentially negative environmental impacts. Residues of metalaxyl, abamectin, alpha cypermetrin, profenofos, chlorothalonil, and deltamethrin were measured in tomato, cabbage, and eggplant samples. HPLC was used to analyze these seven pesticide residues after extraction by QuEChERs method. The detected residue pesticide residues exceeded the standard limits recommended by WHO. Multi-residues contamination was observed in some samples. All seven pesticides were detected in samples collected from three market sites, with Bugarama valley samples showing the highest levels of contamination. This is likely related to the region's higher water availability and warm climate, which attract multiple pests and prompt farmers to apply pesticides excessively and more frequently, without adhering to label instructions. Poor waste management during spraying, lack of skills in pesticide application and personal protective equipment for farmers and pesticide dealers were also identified as the major sources of intoxication and environmental pollution. All calculated aHI values indicated minimal acute health risk from consuming the analyzed vegetables. However, some HQ values suggested that prolonged consumption of eggplant could pose chronic health risks, as HQ values for cyhalothrin (HQ=1.313) and abamectin (HQ=2.15) exceeded the tolerable limit. The findings of this study provide valuable information for health professionals, environmental scientists, and decision makers to raise public awareness about proper pesticide applications and management, thereby protecting consumer health.

## Author contributions

J.B.N. and E.N. collected samples, performed laboratory analyses, and wrote the first draft; A.R. processed the data and contributed to the manuscript writing; T.M. and D.U. mobilized funds, designed the study, and revised the manuscript. All authors read and approved the final manuscript.

## Acknowledgements

Authors express gratitude to the International Science Programme (ISP) of the Uppsala University, Sweden, for financial support. We also appreciatively acknowledge the collaboration with the farmers, local authorities, agro-dealers, fruits and vegetable sellers of Nyamasheke and Rusizi districts of Western Province of Rwanda who have accepted to participate in the survey realized during this study.

## Conflicts of interest

The authors declare that there is no conflict of interest.

## Funding

This research received no specific grant from any funding agency in the public, commercial, or non-profit sectors.

## Ethical consideration

Not applicable.

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