American Journal of Environmental Protection, 2026, Vol. 14, No. 1, 1-7
Available online at http://pubs.sciepub.com/env/14/1/1
Published by Science and Education Publishing
DOI:10.12691/env-14-1-1

Pesticide Residues in Tomatoes from Kenya's Uasin Gishu County: Food Safety Implications and Dietary Risk Assessment

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Received March 20, 2026; Revised April 22, 2026; Accepted April 28, 2026

Abstract Tomatoes are one of the most cultivated and consumed vegetables worldwide. The use of pesticides for crop protection is important; however, their presence in the food web is of great concern to human health. This study aimed to assess the level of pesticide residues in tomatoes sold in common markets of Uasin Gishu County. A total of 300 samples of fresh tomatoes were collected from six sub-counties of Uasin Gishu County. The samples were analyzed to quantify two pesticides using the Quick Easy Cheap Effective Rugged and Safe (QuEChERS) multi-residue extraction, followed by High Performance Liquid Chromatography (HPLC). Health risk assessment was conducted using Target Hazard Quotient (THQ) and Hazard Index (HI) calculations for the population. Lambda-cyhalothrin concentrations ranged from 0.0297 to 0.8502 mg/kg. Approximately 73% of samples exceeded the European Union MRL (0.07 mg/kg), and 60% surpassed the Codex MRL (0.3 mg/kg). The highest concentration of lambda-cyhalothrin was observed in Cheptiret market (0.8502 ± 0.0146 mg/kg). Mancozeb residues were also detected at levels below both the EU (3.0 mg/kg) and Codex (2.0 mg/kg) MRLs. Health risk assessment revealed THQ and HI values below 1.0 for all markets. The highest combined HI for children was 0.088 at Cheptiret market, indicating 8.8% of the threshold for potential adverse health effects. This study demonstrates non-compliance with international pesticide MRLs for lambda-cyhalothrin in tomatoes from Uasin Gishu County markets, highlighting significant gaps in pre-harvest interval adherence and pesticide application practices. While acute health risks appear low based on current exposure models, long-term exposure warrants monitoring, particularly for vulnerable populations. The findings emphasize the need for strengthened continuous residue monitoring and consumer awareness programs to ensure food safety and protect public health in Kenya's horticultural sector.

Keywords: *Tomatoes, Public Health, Lambda-cyhalothrin, Mancozeb, pesticide residues, QuEChERS, HPLC, Maximum Residue Limits, health risk assessment, food safety*

Cite This Article: Leonard Mwetich Muruny, Kiplagat Ayabei, Samuel Lutta, and Stephen Barasa, “Pesticide Residues in Tomatoes from Kenya's Uasin Gishu County: Food Safety Implications and Dietary Risk Assessment.” *American Journal of Environmental Protection*, vol. 14, no. 1 (2026): 1-7. doi: 10.12691/env-14-1-1.

1. Introduction

Pesticides are mainly designed to prevent, kill, defeat, or reduce pests at all stages during cultivation to boost agricultural production [1]. Pesticides ensure high crop yields; different treatments with multiple pesticides are necessary to ensure a good production and reduce the impact of crop diseases [2].

During the application of pesticides in farms, factors such as frequency of application, equipment, mixer conditions, and exposure determine the potential chemical risks to human health. Pesticides have been involved in a wide range of human health hazards, such as headaches and nausea, chronic impacts like cancer, reproductive harm, and endocrine disruption [3].

Monitoring of residual pesticides in crops has been carried out to ensure proper use of pesticides and the safe concentrations of pesticide residues on plants [1]. Vegetables have become one of the major foods in people’s daily diet due to their high nutritional value, providing various vitamins, minerals, dietary fiber, and antioxidants for the human body. The physiological characteristics of vegetables make them more prone to pesticide pollution than other crops [4].

Vegetables are highly susceptible to pests and diseases during their growth. This therefore calls for frequent and diverse use of organochlorine pesticides to control pests, which also ensures the yield and quality of vegetables. Although the use of organochlorine pesticides has brought great economic benefits, their residues in vegetables and health risks to consumers have attracted widespread attention [4].

Human health risk assessment of residual pesticide in vegetable and fruit samples in Gujarat State, India show that the pesticide residue levels in food commodities warrant monitoring owing to their chemical properties striking a direct implication on human health across the globe [5]. It is progressively being recognized that scores of chronic pathologies are closely associated with residual pesticides in food items. Studies have also pointed towards the fact that the adverse effects of cumulative exposure to multiple residual pesticides are more risky than any single exposure [5]. Pesticide poisoning is associated with several disorders such as dyslipidemia, diabetes, liver, kidney, cardiovascular diseases, and fatalities [5].

The export of synthetic pesticides banned for use within the European Union (EU) to developing countries is raising concerns, especially given the growing awareness of evidence that these chemicals pose deadly risks to human health and the environment [6]. The EU is increasingly concerned about the export of these products by firms within the bloc. The overall usage of pesticides is rising in developing countries, that is, countries categorized by the World Bank as low- and middle-income countries (LMICs) [6]. The resulting impacts on human life and the planet are against the United Nations' Sustainable Development Goals (SDGs) and threaten global food safety [6].

In Kenya, tomatoes are widely grown and consumed as a vegetable. However, major challenges in its production include high pest and disease infestation and nutrient deficiency, which, if not controlled, can cause great losses [7]. Increased tomato demand in Kenya has necessitated an increase in production, forcing farmers to rely heavily on pesticides to control pests and diseases, which has led to problems such as contamination of the produce and the environment [7].

In Uasin Gishu, the most commonly applied pesticide along the River Moiben was insecticide with Lambda Cyhalothrin, leading with 31.9 % of the farmers applying it [8]. Lambda Cyhalothrin is meant for killing insects affecting cabbages, kales and tomato crops on farms were applied on irrigated farms along the River Moiben, and their trade names, as given by farmers, were: Pentagon, thunder and Duduthrin. Flubendiamide followed with 17.2% of the farmers applying it on irrigated tomatoes and cabbages and the trade name was Belt [8].

In this regard, this study evaluated the levels of pesticide residues in tomatoes produced in Uasin Gishu County and pesticide application practices that are associated with the accumulation of residues and exposure in fresh tomatoes in Uasin Gishu. This information is useful in improving the food safety system in Kenya and subsequently contributes to protecting and promoting public health groups of plant origin, such as bread and other foodstuffs based on cereal processing.

2. Materials and Method

Apparatus, materials, and chemicals, QUECHERS

All of the pure substances of chromatographic grade (purity ≥ 95%) were received from Sigma Aldrich Corporation Ltd., represented by Kobian Scientific Limited, Kenya. Acidified Milli-Q water was filtered by syringe membrane filters with a size of 0.23 μm, internal diameter 13 mm, before using it in HPLC. Hydrochloric acid (HCl) and sodium hydroxide (NaOH) were used for pH adjustment. Acetone and Acetonitrile (ACN) 98 % (HPLC grade) is from Kobian Limited (Nairobi, Kenya). Analytical standards of λ-cyhalothrin and Mancozeb, of purity ≥ 98%, were obtained from Bio-Medica Laboratories Limited, Nairobi, Kenya. Potassium sulphate 99% and Sodium chloride 98% were purchased from Science Lab Limited, Nairobi, Kenya.

Equipment

Shimadzu LC 20AT HPLC equipment equipped with UV and fluorescence detectors.

Study area

The research was undertaken in River Moiben within Uasin Gishu County in Kenya. The county lies between latitudes 0.334 °N to 0.456 °N and longitudes 35.292 °E to 35.436°E. It lies at approximately 2,100 meters above sea level. The region experiences a moderate tropical climate characterized by two seasons (long rain and short rain), and with temperatures ranging from 10 °C to 26 °C, which creates favorable conditions for year-round agricultural production.

Major crops grown by the smallholder farmers include tomatoes, maize, and vegetables, which are locally irrigated by surface irrigation from the River Moiben. The area has been reported to use a high amount of pesticides to assist in the fight against pest pressure and the improvement of yield. While pesticides play significant roles in the upkeep of pests and increased production of crops, their incorrect or excessive application could lead to toxic residue levels, compromising both the content and the environment.

Sample collection

Tomatoes were sampled from randomly selected vendors to make a composite sample targeting 300 tomatoes in Uasin Gishu County. The study followed a quantitative approach, and residual pesticides in tomatoes were analysed between May and July 2024 to evaluate the level of pesticide residues in tomatoes sold and consumed in Uasin Gishu County.

Three hundred (300) samples of tomatoes were collected from 30 markets within the six sub-counties (Soy, Moiben, Ainabkoi, Turbo, Kapseret, and Kesses) in Uasin Gishu County for analysis. Sample packaging and storage were done according to the Pest Control Board and the Food & Drug Administration. Each sample was kept in a separate sterile Ziploc bag, sealed, labelled with a unique sample identity, placed in an ice box, transported to Laboratory and stored at 4°C until analysis.

Sample Preparation

The tomato samples were sliced and homogenized using a commercial blender with stainless steel blades and a glass vessel. After that, 10 g of this tomato pulp was weighed in a 50 mL Falcon centrifuge tube, and 10 mL of acetonitrile was added using a solvent dispenser. The mixture was vortexed for 30 s. Then, 4 g anhydrous K_2SO_4 and 1 g NaCl were added, and the mixture was vortexed again for 30 s; after that, the tomato pulp and the upper organic acetonitrile extract containing the pesticides were isolated by centrifuging for 5 minutes at 5000 rpm. The cleanup step was carried out by pouring 8 mL of the upper acetonitrile layer into a 15 mL Falcon centrifugation tube and adding 200 mg of PSA sorbent and 1.2 g anhydrous K_2SO_4; after vortexing for 30 s, the mixture was centrifuged for 5 min at 5000 rpm (Anastassiades *et* *al*., 2003). The organic extract was transferred directly into the autosampler vial for its chromatographic analysis, using an HPLC analysis.

Sample Clean-up and Analysis

Four (4.0, 4.1,3,9 and 4.2 mL's) portions of the liquid sample extracts containing pesticides were each pipetted into 15 mL centrifuge tubes. A standard mixture, 20 µL (0.02 µg/g), of each targeted pesticides were added to obtain the targeted pesticide residue levels analysed used in Uasin Gishu County for lambda cyhalothrin and mancozeb. The QuEChERS multi-residue method for analysis of pesticide residues in low-fat products was used for analysis. For sample analysis, 10 µL of formic acid (10 µL per mL of sample) and 60 µL of D-sorbitol (30 µL per sample) were added to each separated liquid sample extract portion in 15 mL centrifuges tube. After shaking vigorously for 1 minute, 500 µL of the mixture was pipetted into a 1 mL auto sampler vial. It was diluted using High Performance Liquid Chromatograph (HPLC) water, vortexed, and taken for analysis using High Performance Liquid Chromatography technique with fluorescence and D2 detectors (LC 20AT- Shimadzu) for 12 minutes at room temperature.

Standard preparation

Stock solutions of λ-cyhalothrin and Mancozeb were prepared by dissolving 100 mg of each powder in 1 mL of acetonitrile, and made up to 1000 mL using the same solvent. Each stock solution was then diluted using mobile phase to prepare the following concentrations: 0, 5, 10, 15, 20, 25ppm. From the obtained standard solutions, calibration curves were plotted as a function of peak areas generated from the chromatogram against concentrations of each pesticide standard. The linearity was expressed using the correlation coefficient (R^2-value) and the intercept value. The obtained regression equations were helpful in the determination of residual concentrations of screened pesticides present in the tomato samples. The pesticide identification was obtained by comparing the recorded chromatograms on each tomato sample to that of the standard of the screened pesticides using the retention time.

HPLC System

The analysis was performed using Shimadzu LC -20AT HPLC equipment equipped with UV and fluorescence detectors. The chromatographic separation was carried out on reversed phase, Phenomenex Luna 150 ×46 µm by × 5µm column. The mobile phase comprised of water and Acetonitrile (40:60). The flow rate of the mobile phase was 1.0 mL, and the injection volume was 20µL, while the column temperature was 30°C. The detection wavelength was set at 230 nm and 350 nm. Total run time was 12 minutes.

3. Results and Discussion

Concentration of Pesticide Residues in Tomatoes in Markets in Uasin Gishu County

This study assessed pesticide residue levels in 300 tomato samples collected from 30 markets across six sub-counties (Soy, Moiben, Kapseret, Kesses, Ainabkoi, and Turbo) in Uasin Gishu County, Kenya. We focused on two commonly used pesticides: lambda-cyhalothrin (a synthetic pyrethroid insecticide) and Mancozeb (a dithiocarbamate fungicide). The findings revealed concerning levels of pesticide contamination that warrant attention in the context of food safety and public health.

Pesticide Residues Detected in Tomato Samples from Soy Constituency Markets

The tomato samples collected from the five markets in Soy constituency showed detectable lambda-cyhalothrin residues. Notably, Nangili market recorded the highest concentration of Lambda-Cyhalothrin at 0.4365 ± 0.0006 mg/kg, followed by Moi's Bridge 0.4303 ± 0.0031, Matunda 0.3178 ± 0.09420, Ziwa 0. 2072 ± 0.0092 mg/kg, and lastly Soy was 0.0813 ± 0.0720. All the concentrations exceeded EU MRLS (0.07 mg/kg). In Comparison to the Codex MRLS of 0.3 mg/kg, three markets exceeded the set standards. These findings align with recent studies in East Africa that have documented elevated pyrethroid residues in horticultural produce due to intensive application practices [9,10]. Mancozeb pesticide was detected in the samples from Soy markets at a concentration below the EU MRLS of 3.0 mg/kg and Codex MRLS of 2.0 mg/kg. Soy was 1.3021 ± 0.0414, Nangili <L.O.D, Matunda 0.7443 ± 0.0188, Moi's Bridge 0.9556 ± 0.0029, Ziwa 0. 2882 ± 0.1292 mg/kg, respectively.

Pesticide Residues Detected in Tomato Samples from Kesses Constituency Markets

The most alarming result was observed in the Cheptiret market, where lambda-cyhalothrin reached 0.8502 ± 0.0146 mg/kg—more than 12 times the EU MRL and nearly three times the Codex limit. All five markets in Kesses constituency exceeded both regulatory standards, with concentrations ranging from 0.3155 mg/kg (Ngeria) to 0.8502 mg/kg (Cheptiret). This pattern suggests widespread non-compliance with pre-harvest intervals and recommended application rates in this region, consistent with observations by [11] who reported similar findings in Kenya's horticultural zones.

Mancozeb pesticide was detected in the samples from Kesses markets at a concentration below the EU MRLS of 3.0 mg/kg and Codex MRLS of 2.0 mg/kg. Burnt forest was 0.4500± 0.000, Bindura 0.6142 ± 0.0154, Kerita 1.3625 ± 0.0776, Cheptiret 1.1788 ± 0.0983, Ngeria 0. 4775 ± 0.0401 mg/kg, respectively. From this result, all the markets had a concentration, all of which were significantly lower than both the MRL of the European Union and Codex.

Pesticide Residues Detected in Tomato Samples from Ainabkoi Constituency Markets

For the 30 tomato samples from five Ainabkoi markets analysed in the laboratory, all the samples had detectable lambda cyhalothrin and mancozeb. KCC had 0.1229 ± 0.0284, Naiberi 0.1277 ± 0.0278, Plateau 0.3349 ± 0.0103, Kipkorgot 0.3813 ± 0.0107, and Munyaka 0. 2573 ± 0.0244 mg/kg concentration of Lambda Cyhalothrin, respectively. All exceeded EU MRLS (0.07 mg/kg), but two out of five markets (Plateau and Kipkrogot) exceeded Codex MRLS of 0.3 mg/kg. The variability in residue suggests heterogeneous pesticide application practices among farmers supplying these markets, a phenomenon documented by [12] in their study of smallholder farming practices in Kenya. Residual Mancozeb was detected in all the tomato samples collected from Ainabkoi markets as follows: KCC was 0.7809 ± 0.2136, Naiberi 0.1841 ± 0.1186, Plateau 1.2929 ± 0.0347, Kipkrogot 0.3080 ± 0.0514, and Munyaka 0. 4179 ± 0.1403 mg/kg, respectively. The results were all within the set standards, both the EU and Codex.

Pesticide Residues Detected in Tomato Samples from Moiben Constituency Markets

For the 30 tomato samples from five Moiben markets analysed in the laboratory, all the samples had lambda Cyhalothrin and Mancozeb pesticide residue levels above the limit of detection (LOD). The results recorded were as follows for lambda cyhalothrin: Bahati was 0.3832± 0.0654, Marura 0.4530 ± 0.0016, Moiben 0.1822 ± 0.0012, Chepkanga 0. 3531 ± 0.0136, and Eldoret Market 0. 4208 ± 0.0122 mg/kg, respectively. All the concentrations for Lambda cyhalothrin exceeded both the EU MRLS and Codex, except samples from Moiben Market, which were within Codex MRL. Marura market showed particularly high levels (0.4530 ± 0.0016 mg/kg), indicating potential overuse or inadequate adherence to recommended withdrawal periods. These findings are consistent with research by [8], who identified lambda-cyhalothrin as the most frequently misused insecticide in the River Moiben irrigation scheme. Mancozeb pesticide was detected in the samples from Moiben markets at a concentration level below the EU MRLS of 3.0 mg/kg and the Codex MRLS of 2.0 mg/kg. Bahati was 0.1822± 0.0208, Marura 0.1410± 0.0310, Moiben 0.5042± 0.0154, Chepkanga 0. 1785 ± 0.0138, and Eldoret Market 1.0037 ± 0.0772 mg/kg, respectively.

Pesticide Residues Detected in Tomato Samples from Kapseret Constituency Markets.

30 tomato samples from five Kapseret markets were analyzed both for lambda Cyhalothrin and Mancozeb pesticide residue levels. For lambda Cyhalothrin, Lemook was 0.2165± 0.0060, Kapseret 0.5408 ± 0.0182, Langas 0.4826 ± 0.0025, Kisumu Ndogo 0. 4957 ± 0.0283, and Pioneer 0. 1924 ± 0.0083 mg/kg, respectively. Three markets (Kapseret, Langas, and Kisumu Ndogo) exceeded both regulatory thresholds, with concentrations ranging from 0.4826 to 0.5408 mg/kg. The relatively high residue levels in this urban-adjacent area may reflect intensive production systems aimed at meeting high market demand, as suggested by [13] in their analysis of peri-urban vegetable production systems. Mancozeb pesticide was detected in the samples from Kapseret markets at a concentration level below both the EU MRLS of 3.0 mg/kg and the Codex MRLS of 2.0 mg/kg. Lemook was 0.6651± 0.1184, Kapseret 1.0187 ± 0.0128, Langas 0.5287 ±0.0052, Kisumu Ndogo 1.0508 ± 0.0172, and Pioneer 0. 3919 ± 0.1680 mg/kg, respectively.

Pesticide Residues Detected in Tomato Samples from Turbo Constituency Markets.

This sub-county showed the most varied results as follows: Turbo had 0.2763± 0.0006, Kipkaren 0.0297 ± 0.0004, Jua Kali 0.0772 ± 0.0018, Roadblock 0. 4129 ± 0.0018, and Kahoya 0.3958± 0.0018 mg/kg, respectively, for Lambda Cyhalothrin. This heterogeneity may reflect differences in farmer training, access to extension services, and awareness of good agricultural practices [14]

Lambda Cyhalothrin was detected in the samples from Turbo markets at a concentration above EU MRLS (0.07 mg/kg) except the Kipkaren market with 0.0297 mg/kg. Additionally, 3 markets were below the Codex MRLS of 0.3 mg/kg, except Roadblock and Kahoya markets. Mancozeb pesticide was detected in samples from 3 markets in the Turbo constituency. However, the concentrations were within the EU MRLS of 3.0 mg/kg and Codex MRLS of 2.0 mg/kg. Turbo was 0.0663± 0.0102, Kipkaren < L.O.D, Jua Kali 0.1414 ± 0.1324, Roadblock <L.O.D, and Kahoya 0. 8238± 0.0307 mg/kg, respectively.

Generally, Mancozeb residues were detected in 83.3 % of samples, with concentrations ranging from below the limit of detection to 1.3625 mg/kg. All detected levels remained below both EU (3.0 mg/kg) and Codex (2.0 mg/kg) MRLs, suggesting better compliance with application guidelines for this fungicide compared to lambda-cyhalothrin.

Comparison with Regional and Global Studies

When the results were compared with other studies from Africa and beyond, the situation is not particularly comforting. The pesticide residue levels found here are on par with, or even higher than, those reported in similar agricultural regions elsewhere on the continent. For example, [15] in Tanzania's Kilimanjaro region observed that 58 % of tomato samples exceeded the legal limit for lambda-cyhalothrin. The concentrations there (0.12–0.45 mg/kg) were lower than those measured in Uasin Gishu County, but the overall trend remains.

Looking at Nigeria, [16] found that 71% of tomatoes from urban markets had pyrethroid residues above the legal threshold, attributing this to insufficient pesticide safety knowledge and limited training among smallholder farmers. [17] took a broader perspective by reviewing data from across sub-Saharan Africa. They concluded that the main factors driving high residue levels are gaps in knowledge, weak regulatory enforcement, and a lack of protective equipment.

On a global scale, the picture does not improve much. [18] noted that in developing countries, violations are often linked to systemic issues such as dysfunctional extension services, weak regulations, and inadequate monitoring. The most recent World Health Organization report (2024) highlights this as well, showing that pesticide residues in African produce are two to five times higher than those in Europe and North America [19].

Health Risk Assessment

Turning to health risks, we calculated both the Target Hazard Quotient (THQ) and Hazard Index (HI) as shown in Table 1 to assess the potential dangers posed by these residues. While none of the markets reached or surpassed the risk threshold (THQ or HI above 1.0), some results were uncomfortably close, especially for children and other vulnerable groups.

Table 1. Health Risk assessment of consumption of pesticides residues in tomatoes in Uasin Gishu Markets

						CYHALO					MANCOZEB					
SUB COUNTY	SAMPLING MARKET	CYHALO	MACOZEB	ADI	ADULT WT	CHILD WT	EDI A	EDI C	THQ A	THQ C	EDI A	EDI C	THQ A	THQ C	HI A	HI C
Ainabkoi	KCC	0.123	0.781	105	70	23	0.184	0.561	0.002	0.005	1.171	3.565	0.011	0.034	0.013	0.039
Ainabkoi	Naiberi	0.128	0.184	105	70	23	0.749	2.278	0.007	0.022	0.276	0.840	0.003	0.008	0.010	0.030
Ainabkoi	Plateau	0.335	1.293	105	70	23	0.502	1.529	0.005	0.015	1.939	5.902	0.018	0.056	0.023	0.071
Ainabkoi	Kipkrgot	0.381	0.308	105	70	23	0.572	1.741	0.005	0.017	0.462	1.406	0.004	0.013	0.010	0.030
Ainabkoi	Munyaka	0.257	0.418	105	70	23	0.386	1.175	0.004	0.011	0.627	1.908	0.006	0.018	0.010	0.029
Kapseret	Lemook	0.217	0.665	105	70	23	0.325	0.988	0.003	0.009	0.998	3.036	0.010	0.029	0.013	0.038
Kapseret	Kapseret	0.541	1.019	105	70	23	0.811	2.469	0.008	0.024	1.528	4.651	0.015	0.044	0.022	0.068
Kapseret	Langas	0.483	0.529	105	70	23	0.724	2.203	0.007	0.021	0.793	2.414	0.008	0.023	0.014	0.044
Kapseret	Kisumu Ndogo	0.496	1.051	105	70	23	0.744	2.263	0.007	0.022	1.576	4.797	0.015	0.046	0.022	0.067
Kapseret	Pioner	0.192	0.392	105	70	23	0.289	0.878	0.003	0.008	0.588	1.789	0.006	0.017	0.008	0.025
Kesses	Burnt Forest	0.459	0.450	105	70	23	0.688	2.094	0.007	0.020	0.675	2.054	0.006	0.020	0.013	0.040
Kesses	Bindura	0.553	0.614	105	70	23	0.830	2.526	0.008	0.024	0.921	2.804	0.009	0.027	0.017	0.051
Kesses	Kerita	0.407	1.363	105	70	23	0.611	1.859	0.006	0.018	2.044	6.220	0.019	0.059	0.025	0.077
Kesses	Cheptiret	0.850	1.179	105	70	23	1.275	3.881	0.012	0.037	1.768	5.381	0.017	0.051	0.029	0.088
Kesses	Ngeria	0.316	0.478	105	70	23	0.473	1.440	0.005	0.014	0.716	2.180	0.007	0.021	0.011	0.034
Moiben	Bahati	0.383	0.182	105	70	23	0.575	1.749	0.005	0.017	0.273	0.832	0.003	0.008	0.008	0.025
Moiben	Marura	0.453	0.141	105	70	23	0.680	2.068	0.006	0.020	0.212	0.644	0.002	0.006	0.008	0.026
Moiben	Moiben	0.182	0.504	105	70	23	0.273	0.832	0.003	0.008	0.756	2.302	0.007	0.022	0.010	0.030
Moiben	Chepkanga	0.353	0.179	105	70	23	0.530	1.612	0.005	0.015	0.268	0.815	0.003	0.008	0.008	0.023
Moiben	Eldoret market	0.421	1.004	105	70	23	0.631	1.921	0.006	0.018	1.506	4.582	0.014	0.044	0.020	0.062
Soy	Soy	0.081	1.302	105	70	23	0.122	0.371	0.001	0.004	1.953	5.944	0.019	0.057	0.020	0.060
Soy	Nangili	0.437	0	105	70	23	0.655	1.993	0.006	0.019	0	0	0	0	0.00624	0.019
Soy	Matunda	0.318	0.744	105	70	23	0.477	1.451	0.005	0.014	1.116	3.398	0.011	0.032	0.015	0.046
Soy	Moi's bridge	0.430	0.956	105	70	23	0.645	1.964	0.006	0.019	1.433	4.363	0.014	0.042	0.020	0.060
Soy	Ziwa	0.207	0.288	105	70	23	0.311	0.946	0.003	0.009	0.432	1.316	0.004	0.013	0.007	0.022
Turbo	Turbo	0.276	0.066	105	70	23	0.414	1.261	0.004	0.012	0.099	0.303	0.001	0.003	0.005	0.015
Turbo	Kipkaren	0.030	0	105	70	23	0.045	0.136	0.000	0.001	0	0	0	0	0.0004	0.00129
Turbo	Jua Kali	0.077	0.141	105	70	23	0.116	0.352	0.001	0.003	0.212	0.646	0.002	0.006	0.003	0.010
Turbo	Road block	0.413	0	105	70	23	0.619	1.885	0.006	0.018	0	0	0	0	0.0059	0.01795
Turbo	Kahoya	0.396	0.824	105	70	23	0.594	1.807	0.006	0.017	1.236	3.761	0.012	0.036	0.017	0.053

Adults: For adults, lambda-cyhalothrin Target hazard quotient (THQ) values ranged from zero in Kipkaren to 0.012 in Cheptiret. The health Index (HI) values for adults remained below 0.03. Mancozeb figures for adults were similar, reaching up to 0.019 in Kerita and Soy. The highest combined HI was 0.029 in Cheptiret and 0.025 in Kerita. Acute toxicity does not appear to be an immediate concern, but with chronic exposure, it becomes a matter to monitor. These findings are consistent with studies from Cameroon [20], where risk quotients were also below the threshold, but still warranted attention.

Children: Children, however, are at greater risk. Because they are smaller and consume more food relative to their body weight, their exposure levels are higher. For children, lambda-cyhalothrin THQs reached up to 0.037 in Cheptiret, and mancozeb THQs went up to 0.059 in Kerita. The combined HI for children peaked at 0.088 in Cheptiret, 8.8% of the threshold value. This is still under the official limit, but concerning, given that children are more susceptible to the neurotoxic effects of pyrethroids [21,22].

A troubling development is that recent research indicates even low levels of pyrethroid exposure can affect children's brain development. [23] reported links between dietary pyrethroid exposure and attention disorders in children, even when exposure was below official safety limits. [24] found cognitive deficits among children in farming communities with high pesticide use. These findings raise an important question: are current safety standards sufficient to protect the most vulnerable populations?

Estimated Daily Intake (EDI) calculations show that for children, exposure to lambda-cyhalothrin from tomatoes ranged from 0.045 to 3.881 micrograms per kilogram of body weight per day. The official safe limit for average daily intake (ADI) is 105 µg/kg bw/day, so these exposures are well below the limit—at least in theory. For mancozeb, EDI ranged from undetectable to 6.220 µg/kg bw/day in children from Kerita. Again, these values are below the ADI, but this does not account for total dietary intake or the combined effects of multiple pesticides. That's why a broader and more realistic approach to risk assessment is needed [25].

Statistical Analysis

Since each location had only one measurement non-parametric Kruskal–Wallis test was used to work out the test of significance. At the 5% significance level, concentrations of both lambda-cyhalothrin and mancozeb differ significantly across sampling points. This indicates uneven pesticide distribution, requiring site-specific monitoring and risk management to protect consumer health [26].

4. Conclusion

This study has demonstrated the widespread presence of pesticide residues, particularly lambda-Cyhalothrin and Mancozeb, in tomatoes sold across various markets in Uasin Gishu County, Kenya. Notably, levels of Lambda-Cyhalothrin in several markets exceeded the maximum residue limits (MRLs) set by both the European Union and Codex Alimentarius, indicating potential health risks to consumers. The validation of analytical methods, including the QuEChERS extraction and chromatographic analysis, confirmed the reliability and sensitivity of the detection process. The study underscores the critical need for improved pesticide management, regulatory enforcement, and awareness among farmers and vendors to ensure food safety and public health protection.

Acknowledgement

We wish to thank the Kenya Government Chemist for the analysis

Author Contribution

Leonard Mwetich Muruny is doing Master of Science Student and he is attached to this work. He did data collection, sample preparation, sample analysis, and wrote up the article. Kiplagat Ayabei, Samuel Lutta, and Stephen Barasa conceptualized the research idea and participated in proofreading and general supervision.

Data Availability

All datasets used in the development of this article are available from the corresponding author upon request.

Declarations

Ethics approval and consent to participate: Not applicable; the tomatoes were purchased just like consumers.

Consent for Publications: Not applicable.

Competing Interests: The authors declare no competing interests.

Funding information: The project did not receive any funding.

Clinical trial number: Not applicable.

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