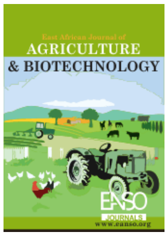

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Original Article

Organophosphate Pesticide Residues in Food Products in Kenya and their Chromatographic Detection: A Systematic Review

Micah Nyabiba Asamba[1*] & *Miriam Wepukhulu*[1]

[1] Tharaka University, P. O. Box 193-60215, Marimanti, Kenya.
* Author for Correspondence https://orcid.org/0000-0001-7667-0981; Email: micahasamba@gmail.com

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Organophosphates, Systematic Review, HPLC, GC-MS, Acceptable Daily Intake, Bioaccumulation.

ABSTRACT

Organophosphate pesticides are used worldwide to control several pests and meet food demand. These chemicals harm non-target animals and people when misused. Thus, they are a health and environmental concern. The purpose of the systematic review was to synthesise the amount, breadth, and quality of evidence from empirical studies concerning the presence, type, and quantity of OPs in food products in Kenya. A systematic review was done by following the PRISMA protocol. For the identification of studies, the following databases were used: Google Scholar, Web of Science, Scopus, and PubMed. The study focused on peer-reviewed articles published between January 2001 and August 2022. Twelve studies met the inclusion criteria for the scoping review. The main methods used in detecting and quantifying organophosphates in the studies were High-Performance Liquid Chromatography (HPLC) and Gas Chromatography-Mass Spectrometry (GC-MS). Most studies (86.67%) reported significant levels of OPs in food products, exceeding the MRLs and the Acceptable Daily Intake (ADIs) set by the World Health Organization. Six of the studies (50%) reported the presence of OPs in plant products (vegetables, cereals, and fruits), while three (25%) found residues in animal products (milk and meat). The most notable OP compounds detected were chlorpyrifos, acephate, profenofos, diazinon, omethoate, and dimethoate. Most of the food samples in the reviewed studies presented contamination, making them a significant risk to human health due to bioaccumulation. Studies done in Kenya for the last 20 years continue to report high levels of organophosphate residues and their metabolites in food products, both from plant and animal origin. Although the residues are below MLRs in some samples, they can accumulate at higher levels in humans, becoming a severe health risk.

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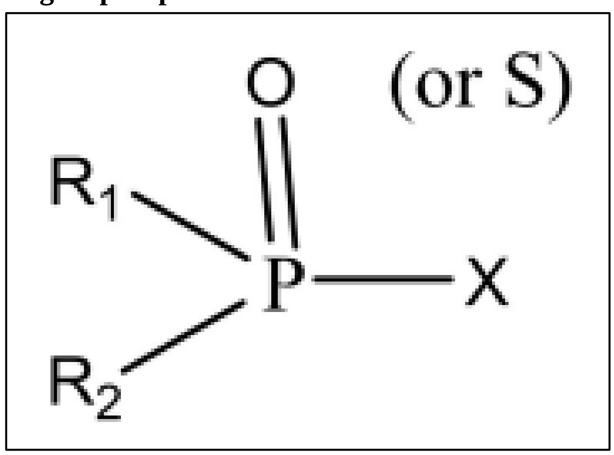
INTRODUCTION

Pesticides can be classified into six based on their function as rodenticides, herbicides, fungicides, insecticides, insect repellents, and fumigants (Fothergill & Abdelghani, 2013; Omwenga et al., 2016). In terms of their chemical structure, they are classified as organochlorines, carbamates, pyrethroids, or organophosphates (OPs) (Farhan et al., 2021). In Kenya, various organophosphate pesticides are used as either acaricides or insecticides, including Chlorpyrifos (CPF), dichlorvos, fenthion, malathion, bifenthrin, fenitrothion, and Diazinon (DZN (Nasef et al., 2019)). They work by inhibiting the enzyme acetylcholinesterase, leading to the accumulation of the neurotransmitter acetylcholine at the nerve endings (Fatunsin et al., 2020). Although they have low persistence, they have high acute toxicity, which has presented novel ecotoxicological challenges (Ilia & Funar-Timofei, 2020).

Chemically, OPs are compounds derived from acids that contain phosphorus (*Figure 1*). OP pesters are amides, esters of thiol derivatives of phosphoric acid (Nasef et al., 2019). Thus, they are easily hydrolysed and so they do not remain in the environment for a long time, unlike the organochlorides. Nonetheless, they have moderate to high toxicity, which is a risk to human health (Farhan et al., 2021). Organophosphate compounds are used as warfare agents, herbicides, fungicides, and insecticides. They are good insecticides due to their cholinesterase inhibition ability, which impairs the nervous systems of the targeted insects (Mdeni et al., 2022). The most commonly applied OPs include chlorpyrifos, diazinon, dichlorvos, parathion, malathion, and fenitrothion (Akan, 2013).

Figure 1: General Structure of Organophosphates



Source: (Mdeni et al., 2022

With the exception of dichlorvos, the majority of OPs have a low vapour pressure, a high oil-water partition coefficient, low volatility, and are only moderately soluble in water. Dichlorvos is the only exception to these characteristics. Some organophosphorus pesticides, such as parathion,

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chlorpyrifos, phosalone, and diazinon, are particularly lipophilic, and as a result, they have the potential to remain in the body for many days or even several weeks in severe cases. For instance, the hydrophobic chemical known as chlorpyrifos (CP) forms strong bonds with sediments as soon as it comes into contact with water. This insecticide is also particularly persistent in sediments due to its half-life of 30 days (Mdeni et al., 2022).

Application of Organophosphate Pesticides in Kenya

Agriculture plays a critical role in the economic and social development of any country and serves as the principal sector and source of livelihood for more than 60% of the population (Farhan et al., 2021). As the world population continues to increase exponentially, there is rising concern about food insecurity (Omwenga et al., 2020). Consequently, various techniques and approaches have been devised to increase yields. Pest management is one of the major and effective approaches used because a lot of food production is diminished because of pest infestation. The use of pesticides to control pests is the most widely used strategy for pest management. Besides, there are some OPs that are used to treat crab lice, head lice, and scabies in hominids (Mdeni et al., 2022).

Globally, the use of pesticides is very common in agriculture because of their role in improving crop yields (Farhan et al., 2021). Organochlorides were favourites for a long time, but they were later eliminated because of their toxicity and long-term persistence in the environment. Consequently, organophosphates emerged as suitable alternatives, generally because they have shorter half-lives. Although they are less persistent, they are still hazardous chemicals (Chawla et al., 2018). Pesticides with organophosphates are used all over the world to get rid of a wide range of pests and meet the growing demand for food (Marete et al., 2021). When these pesticides are used in large amounts and in the wrong way, they hurt animals and people who are not the target. Their leftovers stay in the air, soil, and water for a long time, which leads to biomagnification in the food chain and pests that are resistant to pesticides (Rêgo et al., 2019).

Organophosphate Residues in Food Products

The presence of pesticide residues in food products has been a concern for a long time, especially in vegetables and fruits that are eaten raw (Fothergill & Abdelghani, 2013; Akan, 2013). Exposure through food is more significant in magnitude than through other means such as dermal absorption, drinking water, and air (Kumar et al., 2017). Due to their wide application in public health and agriculture, they lead to significant contamination of food commodities (Nasef et al., 2019). Past researchers have detected OP pesticide residues in food items that include lemons, oranges, beans, tomatoes, pepper, okra, cabbage, lettuce, cucumber, onions, and strawberries (Akan, 2013; Chawla et al., 2018; Yura et al., 2021). Various studies have examined the presence of pesticide residues in soil and water samples in Kenya (Lalah et al., 2003; Musa et al., 2011; Otieno et al., 2014; Anode et al., 2018; Atego et al., 2021), but only a few have explored the presence of these residues in human food products (Macharia, 2015).

Impact of Organophosphate Residues on Health

Pesticides are a public health concern and require regular monitoring to ensure compliance with regulations for food safety and environmental concerns (Fothergill & Abdelghani, 2013). Maximum Residue Limits (MRLs) regulate pesticide residues in crops, and pesticide surveillance aims to ensure compliance with MRLs (Kumar et al., 2017). Health safety limits such as the Acute Reference Dose (ARD) and Acceptable Daily Intake (ADI) have been set for comparison to residue limits in food products (Abraham & Silambarasan, 2016).

Organophosphate pesticides have been linked to various health effects, including cancer, nausea, and headaches, and are associated with endocrine

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disruption, reproductive health concerns, and neurotoxic effects with long-term exposure (Geed et al., 2017). Organophosphate residues in food are linked to various cases of food poisoning recorded in different parts of the world (Ifediegwu et al., 2015; Uniyal et al., 2021; Ambreen & Yasmin, 2021). Milk is an ideal food for dissolving organic pollutants, including pesticides, due to its lipophilic properties (Nasef et al., 2019; Rêgo et al., 2019).

Aims and Objectives

This review uses a systematic literature analysis to describe the landscape of research and highlight gaps in the exploration of OP residues in food products in Kenya. The technique reduces selection bias and ensures complete evidence maps across fields, including materials sciences, public health, agricultural sciences, food technology, nutrition, economics, and environmental sciences. The study aims to develop an interactive open-access evidence map which describes the research volume, range, and nature.

METHODOLOGY

The Systematic Review Method

The study utilises a systematic review approach to summarise the literature to address the study question. The methodology entails a compilation of results from different studies that address the same question (López-Gálvez et al., 2019; Hadei et al., 2021). The review was carried out using steps outlined by Arksey and O'Malley's (2005) protocol, as enhanced by Levac et al. (2010) and Colquhoun et al. (2014) as cited in Teysseire et al. (2020). Five steps were followed in the review: 1) identifying the research question, 2) identifying relevant studies, 3) study selection, 4) charting the data, and 5) collating, summarising, and reporting the results (Teysseire et al., 2020).

Sources, Search Strategy, and Inclusion Criteria

A review was done by following the PRISMA-R protocol (Teysseire et al., 2020; Hadei et al., 2021). For the identification of studies, the following databases were used: Google Scholar, Web of Science, Scopus, and PubMed. The study focused on peer-reviewed articles published between January 2010 and August 2022. The search did not include review articles, letters to the editor, or book chapters. Besides, the articles were organised, and duplicates were removed. Management of the references was done using Mendeley Reference Manager.

The keywords used in the search were as follows: Organophosphates, organophosphorus pesticides, OPPs, OPs; to specify the type of pesticides: food products, food, fruits, vegetables, milk, eggs, meat, grains; to specify the exposure: and Kenya; to specify the study location.

Eligibility Criteria

The inclusion criteria were:

- Studies published in English between 2010 and 2022
- Studies explicitly mentioning Organophosphates used in agriculture
- Studies exploring the presence of OP residues in food products in Kenya

Data Collection and Analyses

A database was developed to enter relevant information from the included studies. It had a form with six sections: information about the article (author, year), location of study, objectives, methodology, and key findings. The analysis of the data was done using Microsoft Excel 2019. A thematic analysis was done and the findings were presented in a narrative format, supported by figures, tables, and graphs.

RESULTS

Organophosphate Residues Detected in Food Products in Kenya

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Twelve studies (n= 12) met the inclusion criteria and were included in the review. *Table 1* summarises the key findings of the studies, including the OPs detected, the methods used for analysis, and the type of sample.

OP residue in Plant and Animal Products

Organophosphate (OP) residues in plant products/crops have been a concern in Kenya, with numerous studies highlighting the presence of these residues in various samples. For instance, the study by Omwenga et al. (2020) examined 90 samples of vegetables and legumes from Nairobi, including French beans, kale, spinach, and tomatoes, and found OP residues in 22% of the samples. The OPs detected included profenofos, omethoate, methamidophos, chlorpyrifos, and acephate. Notably, the EU MRL was exceeded in 21%, 10%, 8% and 22% of the samples, indicating a serious health risk to consumers.

Similarly, Inonda et al. (2015) examined 112 samples of kale and French beans from Nairobi and found that 97% of the samples had detectable OP residues, including dimethoate and chlorpyrifos. These residues were found to be above the set MRIs, indicating an extremely high health risk. Another study by Kariathi et al. (2016) found chlorpyrifos residues above the MRIs in 80% of tomato samples from Meru, Eastern Kenya, which is also a cause for concern.

In contrast, some studies have reported low levels of OP residues in plant products. For instance, Marete et al. (2020) examined samples of tomatoes, French beans, and kales from Meru, Eastern Kenya, and found extremely low residue levels of diazinon and chlorpyrifos, which met the MRLs set by the EU. Ngolo et al. (2019) also found low levels of chlorpyrifos and diazinon in kales and tomatoes from 15 farms in Rift Valley (Laikipia), which met the MRIs set by the EU.

Compared to plant products, fewer studies have explored the contamination of animal food products with OP residues (*Figure 2*). However, some studies have detected OPs in cow milk (Atego et al., 2021; Wanjiku et al., 2022), camel milk (Wanjiku et al., 2022), camel meat (Mbaria et al., 2010), and beef (Mbaria et al., 2010). For example, Atego et al. (2021) found chlorpyrifos residues above the set MRIs in 11% of milk samples from Nakuru, Kajiado, and Kilifi counties, while Wanjiku et al. (2022) detected various OPs in cow and camel milk samples from Central (Kiambu county), Eastern (Isiolo County), and Rift Valley (Laikipia County).

Figure 2: Food Products assessed in the reviewed studies

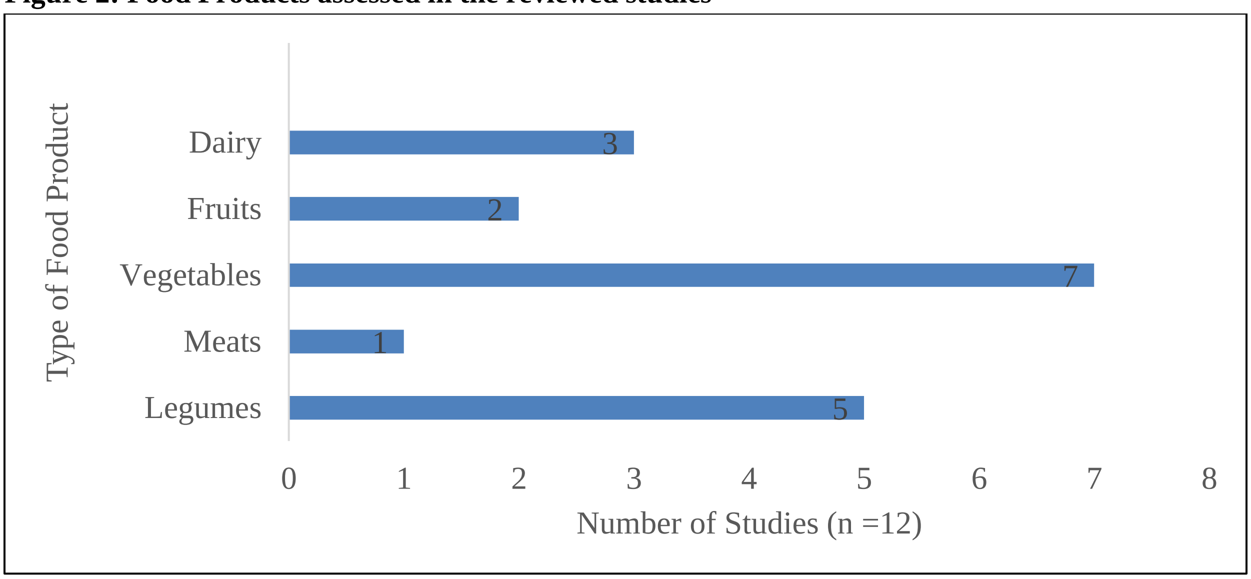

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Table 1: Characteristics of included studies

Author	Region/County	Sample type/sample size	Analytical method	OPs detected	MRLs/EDI	Health Risk Index (HRI)
Omwenga et al. (2020)	Nairobi	Vegetables and legumes: 90 vegetable samples: 19 French beans, 29 kales, 24 spinach and 18 tomatoes	LC/high-resolution tandem MS	Chlorpyrifos (CP), acephate, methamidophos, omethoate, and profenofos.	The EU MRL was exceeded in 21%, 10%, 8% and 22% of the samples	High
Marete et al. (2020)	Eastern (Meru)	Vegetables and Fruits: Tomatoes (1kg), French beans (1kg), and kale (500g)	HPLC	Diazinon, chlorpyrifos	Extremely low residue levels met the MRLs set by the EU.	Extremely low
Ngolo et al. (2019)	Rift Valley (Laikipia)	Vegetables: Kales and Tomatoes 15 farms	Liquid chromatography-tandem mass spectrometry (LC-MS/MS)	Chlorpyrifos, Diazinon	Low residue levels, Met MRIs set by EU	Low risk
(Karanja et al., 2012)	Nairobi	Vegetables: Kales	inductively coupled plasma (ICP) spectrophotometry	Diazinon	Exceeded MRIs set by EU	Moderate
Kipkemoi et al. (2020)	Central (Muranga and Kiambu)	Tomatoes and French beans	GC-MS/MS and LC-MS/MS	Profenofos, Omethoate	29% of tomato samples had omethoate higher than the MRL set by the EU, FAO, and WHO	High
Wanjiku et al. (2022)	Central (Kiambu County) Eastern (Isiolo County), and Rift Valley (Laikipia County)	Milk: 90 cow and 82 camel milk samples	Gas chromatography-tandem mass spectroscopy	Disulfoton, Fenamiphos, Methacrifos, Fenchlorphous, Profenofos Chlorthiophos-2, Coumaphos, Leptophos, Malathion, Tetrachlorvinphos	Mean values were within acceptable limits	Low

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Author	Region/County	Sample type/sample size	Analytical method	OPs detected	MRLs/EDI	Health Risk Index (HRI)
Atego et al. (2021)	Rift valley (Nakuru and Kajiado), Coast (Kilifi)	Milk: 27 milk samples	HPLC, GC-MS	Chlorpyrifos	Above the set MRIs	High
Mbaria et al. (2010)	13 counties across Kenya	Beef (136 samples) and Camel meat (15 samples)	Gas chromatographic method (GLC) and ECD and FID	None of the samples contained quantifiable levels of organophosphate compounds	-	Extremely low
(Inonda et al., 2015)	Nairobi	A total of 112 samples (kales 94, French beans 18)	Gas-liquid chromatography	Dimethoate, Chlorpyrifos	Above the set MRIs	Extremely high
(Kariathi et al., 2016)	Meru, Eastern Kenya	Tomato samples (n =50)	Gas Chromatography-Mass Spectrometry	Chlorpyrifos	Above the MRIs	High
Asamba et al. (2022)	Nakuru, Rift valley	Milk 15 samples	HPLC	Chlorpyrifos	Above MRIs	High
Manduu et al. (2015)	Nairobi County	French Beans (500 g)	GC-MS	Chlorpyrifos, dimethoate	Within Acceptable limits	Low

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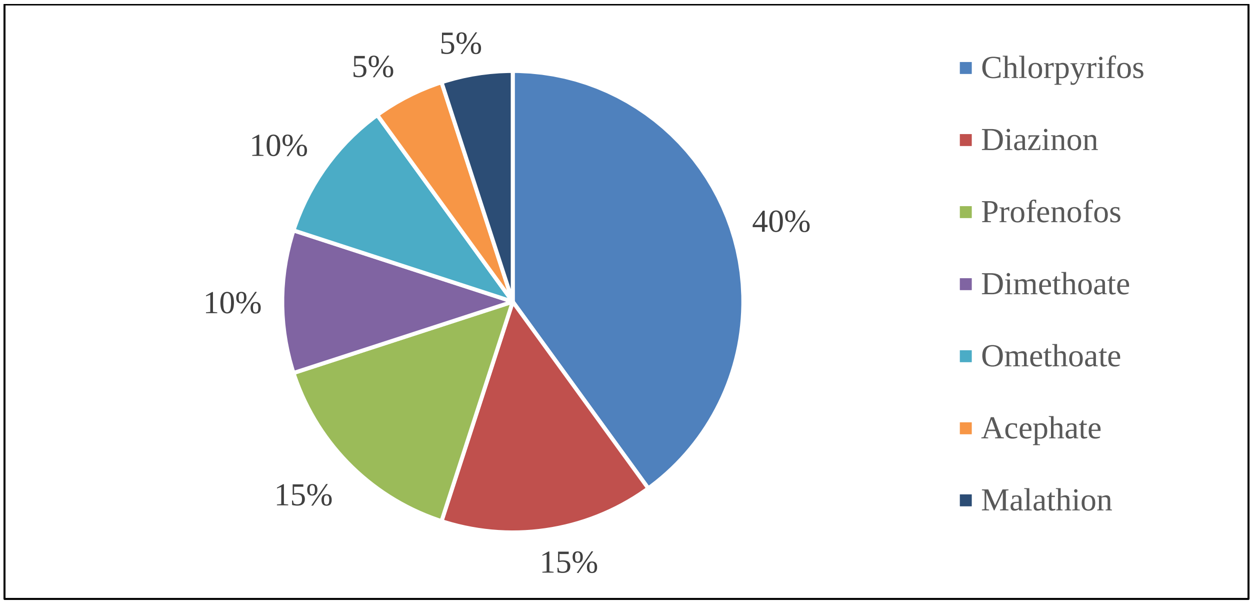
In terms of the OP residues found in the food products, the most dominant one was chlorpyrifos (40% of the studies). It was followed by Diazinon, Profenofos, Dimethoate, Omethoate, Acephate, and Malathion (*Figure 3*).

Figure 3: Organophosphate pesticides reported in the reviewed studies



Extraction Methods for OPs in Food Products and Water

Isolation, fractionation, and separation of residual pesticides from complex food and environmental samples are crucial for reliable analysis and detection. Due to the instability of organophosphate (OP) pesticides, the analysis of their stable derivatives is carried out indirectly using chromatography and other techniques since their concentration is too low to be detected directly (Mdeni et al., 2022). Prior to detection analysis, pesticide enrichment and separation are often necessary. Various enrichment and pre-separation techniques are employed, such as liquid-liquid extraction (LLE) or solid-phase extraction (SPE) for aqueous samples like milk and water and the Soxhlet apparatus for solid samples, although it can be time-consuming.

Recent advancements in technology have led to the development of modern techniques that enable faster and more efficient extraction and separation of pesticides. These techniques include pressurised liquid extraction (PLE), microwave-assisted extraction, dispersive liquid-liquid micro-extraction (DLLME), accelerated solvent extraction (ASE), and Ultrasonic-assisted extraction (UAE). PLE is a popular technique that uses pressure to extract the analyte from the sample in a shorter time, while microwave-assisted extraction uses microwave energy to extract the analyte from the sample. DLLME is a technique that involves the dispersion of a small amount of extraction solvent into the sample solution, resulting in a cloudy mixture, followed by centrifugation to separate the analyte. (Chawla et al., 2018).

Recently, there has been a shift in focus towards the adoption of the quick, easy, cheap, effective, rugged, and safe (QuEChERS) method as a replacement for less efficient extraction methods used in pesticide determination. This method is advantageous as it enables the quantification of a wider range of pesticides from different chemical classes, sometimes even up to hundreds, in a rapid, straightforward, and cost-efficient manner while reducing the amounts of organic solvent and sample

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needed. Additionally, it is an environmentally friendly and multi-residue method suitable for routine high-throughput pesticide analysis, which involves only two steps to minimise errors: (i) a microscale extraction process utilising acetonitrile (ACN) based on partitioning via salting-out and (ii) a dispersive solid-phase extraction (d-SPE) that incorporates a blend of clean-up sorbents such as anhydrous MgSO4 and primary, secondary amine (PSA) to eliminate water traces and matrix interferences (organic acids, fatty acids, and sugars) respectively. This can be done without requiring large volume transfers or solvent exchanges, blending, filtration, or evaporation, enabling a single operator to undertake numerous extractions simultaneously within a brief timeframe

Methods Used for Detection and Quantification of OP Residues in Food Products

The earliest methods used to determine and identify traces of ultra-trace pesticides were fluorometric and spectrophotometric methods (Mdeni et al., 2022). Although the methods are sensitive, they are not very specific. A good method for residue analysis should have low cost, high precision, accuracy, selectivity, and sensitivity applied to a wide range of samples (Mdeni et al., 2022). It is for this reason that currently used techniques include gas chromatography (GC), high-performance liquid chromatography (HPLC), thin-layer chromatography (TLC), and capillary electrophoresis (CE). Some studies use spectroscopy for the detection of pesticides. The method has been shown to be effective in the detection and quantification of OP pesticide dimethoate (Mdeni et al., 2022). GC-MS is often encouraged when dealing with unfamiliar samples. Generally, the use of chromatography techniques is encouraged in many laboratories because of their advanced sensitivity and specificity. Liquid and gas chromatography with different detectors (nitrogen and phosphorus, electron capture detector, and photometric detector) is used immensely for the analysis of residual pesticides. In both LC and GC, mass spectroscopy (MS) is applied to evaluate the residues because of their selectivity and sensitivity (Chawla et al., 2018). *Table 2* gives a summary of the various analytical methods used in the studies.

Table 2: Methods used to analyse Organophosphate residues

Analytical Method	Advantage	Disadvantage
Electrochemical	Quick and simple measurements good detection limits Easy sample preparation of small amount of sample (up to 50 µL using screen printed electrodes).	Total reducing power Not selective to a family of molecules unless the electrode is modified
solid-phase microextraction (SPME)	Allows attainment of satisfactory LODs and cleaner chromatograms for volatile analytes SPME in combination with GC/MS or LC is a solvent-free or almost solvent-free procedure, obviating the need for further preparation steps	SPME fibres are not uniformly sensitive to all compounds
GC-MS	Very good recovery value Sensitive method	Not capable of directly analysing compounds that are non-volatile, polar, or thermally labile
Thin-layer chromatography (TLC)	The equipment needed is inexpensive, Convenient and simple to use. Consumes smaller amounts of solvents	Preparative applications are limited. Oxidation may occur if the TLC plate is stored for a while since a large surface is exposed to atmospheric oxygen
HPLC	High-quality separations are achievable. Coupling with MS is well established	More time-consuming and expensive

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Multi-Residue Methods

The prevalent method for analysing numerous agrochemicals in a single examination is to use multi-residue analysis, as there are a large number of pesticides available on the market. This approach enables the detection of numerous metabolites by simultaneously analysing the active components of many pesticides in a single sample. When assessing the health risks associated with foods, multi-residue analysis is frequently utilised to determine the levels of organophosphates (OPs). International agencies and national regulatory bodies have published validated methods for sampling, sample storage and transportation, sample processing, and analysis. After proper extraction and purification of samples, gas chromatography with electron-capture detection is typically used for analysis. For some OPs, high-resolution gas chromatography-mass spectrometry with stable-isotope labelled analogues is preferred as an internal standard. To obtain dependable data, key analytical issues include sensitivity in the parts-per-trillion range and the resolution of specific isomers, as their toxicities may differ by orders of magnitude.

DISCUSSION

OP residues in Food Products in Kenya

Generally, there was a high frequency of detection of OP residues and metabolites in the studies conducted in Kenya, indicating a significant level of contamination in the environment and food chain. The widespread use of chemical pesticides is largely attributed to Kenya's hot and humid tropical climate, which favours the growth of pests, weeds, and disease vectors. Pesticides are essential for maintaining crop productivity and controlling the spread of infectious diseases in livestock. However, the excessive use of pesticides, inappropriate application methods, and inadequate regulations have contributed to the contamination of the environment and food chain with pesticide residues (Omwenga et al., 2020). The persistence of OP pesticides in the environment is a major concern as they can accumulate in soil and water, leading to long-term contamination and posing a risk to human and animal health. The widespread use of these pesticides in Kenya is likely due to the hot and humid tropical climate, which encourages the growth of pests, weeds, and disease vectors (Omwenga et al., 2020).

The OP residues detected in the studies conducted in Kenya include chlorpyrifos, diazinon, malathion, and pirimiphos-methyl, which are commonly used in the country. The levels of OP residues found in various food commodities, including cereals, fruits, vegetables, and animal products, were mostly above the maximum residue limits set by regulatory agencies. The high levels of OP residues in food commodities pose a significant health risk to consumers, particularly vulnerable populations such as children, pregnant women, and the elderly. OP pesticides are known to be neurotoxic, and chronic exposure to low levels of these chemicals has been associated with various health problems, including developmental delays, behavioural changes, and cancer. Therefore, there is an urgent need to adopt sustainable pest management practices and enforce strict regulations to minimise the contamination of the environment and food chain with pesticides.

Pesticides prohibited in Europe and other nations, including omethoate, dimethoate, methamidophos, acephate, profenofos, and chlorpyrifos, are still used in developing countries, such as Kenya. Developed nations such as the USA, Canada, and the EU have pesticide monitoring programs, but little effort has been concentrated on lasting adverse health impacts on agricultural workers and local consumers in underdeveloped countries (Omwenga et al., 2020). Due to their toxicity to animals, people, and the environment, several of the detected OPs have been banned in Europe and other industrialised countries. Some removed pesticides are still used in Kenya despite European limitations and efforts to adopt less dangerous chemicals, threatening the environment and the health of citizens.

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Chlorpyrifos is considered one of the most effective OP pesticides against a wide range of pests and is still widely used globally, including in Kenya (Karanja et al., 2012). The high levels of Chlorpyrifos residues detected in food products may be due to its absorption from contaminated soil, which could potentially lead to the exposure of humans and animals to toxic levels of Chlorpyrifos (Kariathi et al., 2016). Omwenga et al. (2020) reported the detection of omethoate in 15% of the vegetable samples analysed, despite not being required to be used in vegetables and fruits. This highlights the potential for contamination from neighbouring fields where omethoate is sprayed. Similarly, Kipkemoi et al. (2020) found that 29% of tomato samples analysed had omethoate levels above the maximum residue limit (MRL), indicating a potential health risk to consumers.

The study by Inonda et al. (2015) found that peri-urban Nairobi kales and French beans had residues of chlorpyrifos and dimethoate at levels of up to 100 and 700 g/kg, respectively. According to the findings of that study, pesticide concentrations were found to be higher during the dry season as compared to the wet period, despite the fact that there was no statistically significant difference between the two. It has been shown that pesticide residues change with the changing of the seasons, a situation that contributes to an erroneous assessment of total pesticide exposure. Pesticide residues were observed in French beans compared to kales, which Inonda et al. (2015) attributed to the coarse and thick texture of French beans, which slows the rate of volatilisation, a process by which pesticides disperse.

Pesticides may be administered directly to the soil, mixed into the top few inches, or sprayed on crops. Pesticides may pollute groundwater and surface runoff following storms. Pesticide physicochemical parameters, soil and water properties (clay minerals, organic matter, pH), climate, biology, and other elements affect pesticide fate in soil and water. In most of the included studies, the pesticide residues were above the MRLs. Pesticide residues below the MRL set by the European Commission are not thought to be dangerous to people or the environment because they are so much lower than the concentrations at which harmful effects on people's health or the environment can be found during pesticide safety testing.

In one study that compared residues in cow and camel milk, it was noted that cow milk is relatively more contaminated than camel milk. One explanation for this observation is that dairy farming is often carried out in agriculture-intensive areas where there is widespread use of pesticides (Wanjiku et al., 2022). Camels are kept by pastoralists, who do not practice large-scale agriculture.

Implications for Human Health

MRLs are determined by Good Agricultural Practice and must be followed by pesticide traces left behind (GAP). Due to the fact that GAP may vary from country to country, MRLs can also be varied. When local MRLs are exceeded, this is an indicator that the local GAP is not being followed as closely as it should be. In Kenya, there are no national MRLs that have been established (Omwenga et al., 2020). Data monitoring for OP levels in the environment is very poor, especially in developing countries. This is due to the fact that sampling at key periods of the year may be very expensive, and the analysis of organic substances needs suitable facilities, which can add to the overall cost of the project. Food safety, regulations, product liability, quality, research, and food labelling frequently need analytical monitoring for residues. Many nations regulate the amount of these residues in food. Many small-scale farmers are uninformed of pesticide hazards. In an earlier study done in Ghana, 45% and 20% of farmers sprayed pesticides on cocoa plants while wearing partial or no personal protection equipment, placing them at risk of chemical exposure (Okoffo et al., 2016).

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As shown from the review, there is a widespread presence of OP residues in food products in Kenya. Therefore, it is important to eradicate the pesticides because of their extended partial lives in water and soil for a long time, their resistance to microbial attack, their toxicity, and their high potential for bioaccumulation (Chawla et al., 2018). Fruits and veggies are nutrient-rich. Five or more servings of fruits and vegetables per day are recommended to prevent vitamin deficiency and major illnesses like cancer, heart disease, and obesity. Nonetheless, the use of pesticides during production often leads to the presence of pesticide residues in fruits and vegetables after they have been harvested. Residues from pesticides are dangerous because they may have a negative impact on reproductive systems and the development of foetuses, in addition to having the potential to cause cancer and asthma.

Humans are exposed to OPs through inhalation, via the skin, or the consumption of residues in food. In Kenya, exposure to residues has been reported in different segments, including household members during the home application, agricultural workers and their families, the general public, and those who live near large farms. Thus, OP residues and metabolites are present in the breast milk, urine, serum, and blood of humans (Omwenga, 2021). As neurotoxicants, OPs exert their impact on the nervous system. Since the chemicals are not species-specific, they affect different animals, including mammals, birds, and fish. It should be noted, however, that OPs are not as persistent as organochlorines in the environment, despite their high acute toxicity. Nonetheless, considering that high levels of residues and metabolites were detected in the reviewed studies, it can be concluded that the health of people, especially children, in those regions is at increased risk.

The removal of various categories of pesticides has recently been explained in great detail using a variety of methods, including microfiltration (Doulia et al., 2016), bio-purification systems containing bio mixtures of coconut fibre, compost, and soil (HueteSoto et al., 2017), and conductive diamond photoelectrochemical oxidation (Rubí-Juárez et al., 2016). Additionally, a particular class of Gram-positive bacteria known as actinobacteria have the capacity to extensively break down organophosphorus insecticides (Asamba et al., 2022). Due to their mycelial growth, relatively quick growth rates, capacity to colonise semi-selective substrates, vulnerability to genetic manipulation, and ability to produce surfactants, strains of the Streptomyces genus are widely used for the bioremediation of environments contaminated with organophosphorus pesticides. These traits may also hasten the bioavailability of toxic compounds (Swati & Hait, 2017).

It is quite challenging to compare data from different food categories and geographical areas because the literature currently available on OP concentrations in foodstuffs differs substantially in terms of the OPs used, sampling methodologies, and analytical methods. Therefore, a more accurate comparison of OP levels among various food categories as well as from different sampling regions may result from the development of an appropriate multi-residue methodology to modify the extraction, isolation, and separation processes, as well as the establishment of universal analytical criteria for measuring the above priority OPs and even additional OPs in foodstuffs. It would be best to use a consistent sample collection method for future OPs in food matrices studies, ideally in the same food category, and to provide the method detection limit, range, geometric mean and/or median of individual and total OPE concentrations.

CONCLUSION AND FUTURE PROSPECTS

The review focused on the detection of OP pesticides in food products in Kenya and emphasised the importance of monitoring pesticide residues in food to establish safe levels. The widespread use of pesticides has led to concerns about the potential risks posed by their residues in food products. The establishment of MRLs by various countries and organisations is essential to

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ensure the safety of consumers. The presence of OP residues above MRLs in food products can be potentially hazardous to human health. The high persistence of these pesticides in the environment and their potential for bioaccumulation underscores the importance of their elimination for the health of living organisms.

To prevent pesticide residues in food products, farmers must strictly adhere to pesticide standards, and regular monitoring of pesticide residues in horticulture goods in Kenya is essential to ensure compliance with MRLs established by different organisations. Additionally, good agricultural practices should be followed to reduce the use of chemical pesticides. It is necessary to develop quick, reliable, and cost-effective technologies that can be easily implemented on the worksite to address the environmental issues associated with the accumulation of OPs in food goods and water supplies. The development of simpler extraction and clean-up procedures can also speed up the analysis process.

In conclusion, the review highlights the need for more comprehensive monitoring efforts to ensure the safety of food products for consumers. The implementation of good agricultural practices and the development of new technologies can help reduce the use of pesticides and prevent their accumulation in the environment. The development of simpler analysis methods can also improve the efficiency and accuracy of pesticide residue analysis.

CONFLICT OF INTEREST

There are no conflicts to declare.

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