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Analysis of Pesticide Residues in Tomatoes and French Beans from Murang'a and Kiambu Counties, Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Author EK designed the study, collected samples from farms and markets, analyzed the samples for pesticide residues and wrote the first draft of the manuscript. Authors WAA, ECN and BP advised and supervised. Author EK corrected the draft manuscript and approved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Poor Pesticide-handling practices during production of tomatoes and French beans pose adverse health and environmental effects. This study was conducted to determine the concentrations of pesticide residues in tomatoes and French beans grown and sold in Murang'a and Kiambu counties, Kenya. Samples were collected in farms and markets during the wet and dry seasons. Pesticide residues were extracted using the QuEChERS method and quantified using GC-MS/MS and LC-MS/MS. The recoveries of pesticides from spiked samples were within the acceptable range (70-120%) for quantitative pesticide residue methods. The concentration range of pesticides residues in tomatoes were: profenofos, <LOQ to 0.18 mg/Kg; omethoate, <LOQ to 0.03 mg/Kg; indoxacarb, <LOQ to 0.05 mg/Kg; chlorantraniliprole <LOQ to 0.11 mg/Kg; spirotetramat <LOQ to 0.01 mg/Kg; and metalaxyl < LOQ to 0.02 mg/Kg. The concentration range of pesticides residues in French beans were: imidacloprid <LOQ to 0.29 mg/Kg; chlorantraniliprole <LOQ to 0.37 mg/Kg;

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spirotetramat <LOQ to 0.01 mg/Kg; indoxacarb <LOQ to 0.05 mg/Kg; and metalaxyl <LOQ to 0.02 mg/Kg. The concentrations of pesticide residues in tomatoes and French beans were below the Maximum Residue Levels set by the Joint FAO/WHO Food Standards Programme and the European Union except for concentrations of omethoate in tomatoes, which were higher in 29% of analyzed samples. The presence of omethoate in tomatoes, whose use in vegetables is banned, suggests poor pesticide handling practices by some tomato farmers in the two counties.

Keywords: Pesticides; residues; tomatoes; French beans; health effects; vegetables.

1. INTRODUCTION

Tomatoes (*Lycopersicon esculentum* L.) and French beans (*Phaseolus vulgaris* L.) are extensively grown in several regions of Kenya [1]. Tomatoes are mainly produced for local consumption as a nutritious source of vitamins and phytochemicals including carotenoids, phenolic and ascorbic acids [2,3]. French beans are primarily grown for export to the European Union, South Africa and the Middle East [4,5].

Tomato and French bean production in Kenya is constrained by several factors including pests and diseases [6]. The most important tomato pests are the tomato leaf miner, aphids, whiteflies, thrips, the African bollworm and root knot nematodes [6,7,8]. The main diseases of tomatoes are the bacterial wilt, early and late blights and fusarium wilt [6,7,8]. Common French bean insect pests are thrips, aphids, whiteflies, red spider mites, bean flies and beetles, African bollworm and cutworms [5,9]. The most prevalent diseases of French beans are the bacterial wilt, the common and halo blights, fusarium root rot, damping off, powdery mildew, leaf spots, rust, white mold and the bean common mosaic [10].

Chemical pesticides are extensively used in Kenya to control insect pests and diseases in tomatoes and French beans that lower yields, and in some instances cause complete losses of produce. The active substances in commonly used insecticides include acetamiprod, chlorantraniliprole, abamectin, chlorpyrifos, imidacloprid and betacyfluthrin, λ -cyhalothrin, α -cypermethrin and bifenthrin [10,11]. Blights and fungal diseases are usually controlled using copper-based fungicides (e.g. copper hydroxide) and other fungicides such as mancozeb, metalaxyl, triforine, propineb, xymoxanil and carbendazim [9,10,11].

Pesticide residues have been detected in tomatoes and French beans produced in Kenya due to poor pesticide handling practices

especially by small-scale farmers. A study by Marete and co-workers found residues of carbendazim, imidacloprid, acetamiprid, azoxystrobin, chlorpyrifos and metalaxyl in tomatoes and French beans grown in Meru County [12]. In another study, tomatoes grown in Ewaso Narok wetland, Laikipia County contained fourteen pesticide residues [13]. The concentrations of cyproconazole I and II, fenpropathrin and spiroxamine exceeded the maximum residue levels (MRLs) set by the European Union [13]. Dimethoate and chlorpyrifos residues were found in French beans samples obtained from markets in Nairobi and its environs [14]. Consumption of vegetables containing pesticides residues can cause adverse health effects including endocrine disruption, reproductive disorders and dermatologic, genotoxic and carcinogenic effects [15,16,17]. The aim of this study was to determine the concentration of pesticide residues in tomatoes and French beans grown and sold in Murang'a and Kiambu counties.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Murang'a and Kiambu Counties (Constitution of Kenya, 2010: www.kenyalaw.org) located in the central region of Kenya (Fig. 1). In Murang'a County, the study was conducted in Murang'a East (0.7237°S, 37.1607°E), Murang'a South (0.7895°S, 37.1276°E) and Kandara (0°53'59.99"N, 37°00'0.00"E) Sub-Counties while in Kiambu County, the study was conducted in Thika Sub-County (1.0388°S, 37.0834°E).

The climate in the study area is mainly controlled by altitude. The lower regions of the two counties receive an average annual rainfall exceeding 900 mm while the upper regions bordering the Aberdare Mountains receive an average annual rainfall exceeding 1400 mm [18]. The study area experiences bimodal annual rainfall with long rains falling between the months of March and

May and short rains falling between the months of October and December. Temperatures increases gradually from the lower regions to the upper regions bordering the Aberdare Mountains [18]. The geology of the region consists of basement system rocks in the lower regions and volcanic rocks in upper regions bordering the Aberdare Mountains [18]. The study area has deep red soils composed of weathered volcanic materials [18].

2.2 Collection of Samples

The purposive sampling technique was used to collect tomato and French bean samples from farms and markets in the study area during the

wet season (December, 2019) and the dry season (March, 2020). Tomato and French bean samples were collected from selected farms and markets in Murang'a County (Murang'a East, Murang'a South and Kandara Sub-Counties) and Kiambu County (Thika Sub-County). Six sampling points (Table 1) were selected in each Sub-County.

Representative tomato and French bean samples of about one kilogram were collected at each sampling point, wrapped in aluminium foils, packed in self-sealing bags and put in an ice box. The samples were then transported to the laboratory and stored at $-18^{\circ}\text{C} \pm 5^{\circ}\text{C}$, prior to analysis.



Fig. 1. Map of Murang'a and Kiambu Counties showing the study area (drawn from GIS shapefiles derived from Kenya IEBC boundary dataset)

2.3 Analysis of Samples

2.3.1 Sample pretreatment

Samples were washed with 8% deactivated alumina and de-ionized water. 1 Kg of the cleaned sample was cut into small coarse pieces with a knife then chopped and homogenized with a Hobart food processor. The sample was then blended with the Waring blender until it became paste-like. Homogenized samples were then stored frozen at $-18^{\circ}\text{C} \pm 5^{\circ}\text{C}$ prior to analysis.

2.3.2 Extraction of pesticide residues

Samples were extracted using the Quick, Easy, Cheap, Effective, Rugged and Safe (QuEChERS) method described in the literature [19,20]. $10.0 \text{ g} \pm 0.1 \text{ g}$ of the frozen homogenized sample was weighed into a 50 ml centrifuge tube and $50 \mu\text{l}$ of the internal standards Dichlorvos D6 (10 ppm) and Malathion D10 (10 ppm) added to achieve a final concentration of $0.05 \mu\text{g/g}$ in the sample. $10 \text{ ml} \pm 0.2 \text{ ml}$ of acetonitrile was then added to the tube. The tube was closed and shaken vigorously for 1 min at 1000 rpm using a Geno/Grinder®. Then 6.5 g of premixed QuEChERS extraction salts (containing $4 \text{ g} \pm 0.2 \text{ g}$ magnesium sulphate anhydrous, $1 \text{ g} \pm 0.05 \text{ g}$ sodium chloride, $1 \text{ g} \pm 0.05 \text{ g}$ trisodium citrate dihydrate and $0.5 \text{ g} \pm 0.03 \text{ g}$ disodium hydrogen citrate sesquihydrate) was added to tube. The tube was closed, shaken vigorously by hand to avoid caking and further shaken for 1 min at 1000 rpm using a Geno/Grinder®. For Liquid Chromatography with tandem Mass Spectrometry (LC-MS/MS) analysis, an aliquot of $500 \mu\text{l}$ of the extract was transferred to a 2.0 ml vial and $495 \mu\text{l}$ of HPLC grade water and $5 \mu\text{l}$ of injection internal standard dimethoate D6 (10 ppm) added to the vial. The resultant solution was then vortexed to mix. For Gas Chromatography-Mass Spectrometry / Mass Spectrometry (GC-MS/MS) analysis, $500 \mu\text{l}$ of the extract was transferred into a 2.0 ml vial, blown with nitrogen gas to near dryness and reconstituted with $495 \mu\text{l}$ of isooctane and $5 \mu\text{l}$ of injection internal standard gamma HCH D6 (10 ppm). The reconstituted solution was vortexed to mix.

In addition, $10.0 \text{ g} \pm 0.1 \text{ g}$ of a control sample was weighed into a 50 ml centrifuge tube and fortified with the spiking mixture to achieve the required spiking level (i.e. $0.01 \mu\text{g/g}$ for LC-MSMS and GC-MSMS). $50 \mu\text{l}$ of the internal standards Dichlorvos D6 (10 ppm) and Malathion D10 (10 ppm) were then added to achieve a final concentration of $0.05 \mu\text{g/g}$ in the sample. The control sample was then extracted following the same procedure used to extract pesticide residues from tomatoes and French beans samples. The extract was then prepared for LC-MS/MS and GC-MS/MS analysis following procedures used for extracts of tomatoes and French beans.

Control blanks were prepared using a control matrix without detectable pesticide residues. The control matrices were extracted following same procedure used to extract pesticide residues from tomatoes and French beans samples. For LC-MS/MS analysis, 4 ml of the extract was transferred in a 15 ml centrifuge tube, 4 ml of HPLC grade water added and the resultant solution vortexed to mix. For GC-MS/MS analysis 6 ml of extract was evaporated to dryness using a rotary evaporator and reconstituted with 6 ml isooctane.

2.3.3 Quantification of pesticide residues

Pesticide residues were quantified using the GC-MS/MS and the LC-MS/MS analytical methods. The GC-MS/MS analysis was performed using a Shimadzu GCMS-TQ8040 NX Triple Quad GC-MS/MS equipped with a Restek Rxi-5Sil MS capillary column. $1 \mu\text{L}$ of the sample was injected in splitless mode into an injector port maintained at 250°C . The oven temperature was raised to 300°C at a ramp rate of 10.0°C/min and held for 3 min. The total flow rate of the helium carrier gas was 30.0 mL/min .

The LC-MS/MS analysis was performed using an Agilent LC-MS/MS 6430 LC-MS/MS equipped with a Zorbax Eclipse Plus C18 column. $1 \mu\text{L}$ of the sample was injected into the mobile phase (flow rate = 0.30 mL/min) using the standard injection mode. The concentration of each pesticide residue calculated from its calibration curve using the following formulae:

$$\text{Concentration in } \mu\frac{\text{g}}{\text{g}} = \frac{(\text{C sample} * \text{final volume of extract (ml)})}{\text{sample weight (g)}} \times \text{dilution factor}$$

Where C sample is the amount of pesticide in $\mu\text{g/ml}$ read from calibration curve.

Table 1. Sampling points in Murang'a and Kiambu Counties

Sub-County	Sample Code	Site/ Locality
Murang'a East (ME)	071/01	Murang'a town open air market
	071/02	Mukuyu open air market
	071/03	Kiriaini (farm)
	071/04	Kahuro (farm)
	071/05	Magunas supermarket
	071/06	Kiharu (farm)
Murang'a South (MS)	061/01	Ichagaki (farm)
	061/02	Kenol (farm)
	061/03	Saba saba (farm)
	061/04	Maragua open air market
	061/05	Kaharo (farm)
	061/06	Nginda (farm)
Kandara (KAN)	051/01	Kabati open air market
	051/02	Gatitu (farm)
	051/03	Gaichanjiru (farm)
	051/04	Kagaa (farm)
	051/05	Kirere (farm)
	051/06	Kagunduini open air market
Thika (TKA)	041/01	Makongeni open air market
	041/02	Witeithie open air market
	041/03	Thika town central market
	041/04	Tuskys supermarket
	041/05	Society supermarket
	041/06	Mathai supermarket

3. RESULTS AND DISCUSSION

3.1 Methods Validation

The percent recoveries of the pesticide residues from French beans and tomatoes using the QuEChERS method were: metalaxyl (82.80%), chlorantraniliprole (86.22%), spirotetramat (90.61%), imidacloprid (97.17%), omethoate (101.55%), indoxacarb (103.15%), and profenofos (110.26%). These recoveries were within the commonly accepted range for quantitative pesticide residue methods [21]. The regression coefficient of determination (R^2) obtained from the calibration curves were ≥ 0.99 , indicating an excellent linear relationship between the concentration of each individual pesticide and the GC-MS/MS and/or LC-MS/MS detector response [22]. The limit of quantification (LOQ) for all analyzed pesticide residues was 0.01 mg/Kg.

3.2 Concentrations of Pesticide Residues in French Beans

The concentrations of pesticide residues in French beans during the wet and dry seasons

are shown in Table 2. The concentrations of imidacloprid in French beans during the wet season ranged from <LOQ to 0.09 mg/Kg and from <LOQ to 0.29 mg/Kg during the dry season. The percentage of samples with imidacloprid concentrations above the LOQ during the wet and dry season were 41.7% and 45.8%, respectively. The concentrations of imidacloprid in all samples from Murang'a East were above the LOQ. The concentration of imidacloprid in most samples were higher than the maximum concentration of 0.021 mg/Kg obtained in French beans grown in Meru County, Kenya [12]. The concentrations of imidacloprid in French beans in all samples from the study area are significantly lower than the Maximum Residue Level (MRL) of 2.0 mg/Kg set by the Joint FAO/WHO Food Standards Programme [23] and the European Union [24].

The concentrations of chlorantraniliprole ranged from <LOQ to 0.37 mg/Kg during the wet season. The percentage of samples with concentrations above LOQ was 25%. The concentrations of chlorantraniliprole were <LOQ in all samples during the dry season. The concentrations of chlorantraniliprole in all samples were lower than

the MRL value of 0.8 mg/Kg set by the Joint FAO/WHO Food Standards Programme [23] and the European Union [24].

The concentrations of spirotetramat in all samples from Murang'a East and Kandara sub-counties were below the limit of quantification. The concentration of the two positive samples, each from Murang'a South and Thika was 0.01 mg/Kg. The concentrations of spirotetramat were <LOQ in all samples during the dry season. The concentration of the two positive samples is two order of magnitude lower than the MRL value of 1 mg/Kg set by the Joint FAO/WHO Food Standards Programme [23] and the 1.5 mg/Kg MRL value set by the EU for spirotetramat and its four metabolites [24].

The concentrations of indoxacarb during the wet season were <LOQ in all samples except for one sample from Thika sub-county, which had a concentration of 0.05 mg/Kg. The concentrations of indoxacarb were <LOQ in all samples during the dry season. The positive concentration is lower than the MRL value of 0.5 mg/Kg set for indoxacarb by the EU [24].

The concentration of metalaxyl in all samples during the wet and the dry season were <LOQ except for sample 061/02 from Murang'a South sub-county, which had a concentration of 0.02 mg/Kg during the two seasons. The concentration of metalaxyl in the positive sample was below the MRL value of 0.5 mg/Kg set by the EU [24]. Marete and co-workers obtained considerably higher concentrations (BDL-0.105 mg/Kg) in some French beans grown in Meru County [12].

3.3 Concentration of Pesticide Residues in Tomatoes

The concentrations of pesticide residues in tomatoes during the wet and the dry season are shown in Table 3. The concentrations of profenofos were <LOQ in all samples during the wet seasons and ranged from <LOQ to 0.18 mg/Kg during the dry season. The concentrations of profenofos in all samples were considerably lower than the MRL value of 10 mg/Kg set for tomato by both the Joint FAO/WHO Food Standards Programme [23] and the European Union [24].

The concentrations of omethoate were <LOQ in all samples during the wet seasons and ranged from <LOQ to 0.03 mg/Kg during the dry season. The concentrations of omethoate in 29% of

analyzed samples were higher than the MRL value of 0.01 mg/Kg set for tomato by both the Joint FAO/WHO Food Standards Programme [23] and the European Union [24]. The use of omethoate and dimethoate (its metabolic precursor) on fruits and vegetables is currently banned in Kenya [25]. However, illegal use of dimethoate in tomato production has been documented in Kenya and attributed to its effectiveness and market availability [14,26]. Omethoate has several adverse health effects including endocrine disruption, neurotoxicity and cholinesterase inhibition [27].

The concentration of chlorantraniliprole in all samples were <LOQ during the wet season except for sample 061/05 from Murang'a South, which had a concentration of 0.11 mg/Kg. In addition, only two samples had concentrations >LOQ during the dry season. The concentrations of chlorantraniliprole in the three samples were significantly lower than the MRL value of 0.6 mg/Kg set for tomato by both the Joint FAO/WHO Food Standards Programme [23] and the European Union [24].

The concentrations of spirotetramat in the six positive samples during the wet season were 0.01 mg/Kg. The concentrations were <LOQ in all samples during the dry season. The concentrations of spirotetramat in all samples were significantly lower than MRL value of 2.0 mg/Kg set for tomato established by the European Union [24].

The concentrations of indoxacarb were <LOQ in all samples during the wet season and ranged from <LOQ to 0.05 mg/Kg during the dry season. The concentrations of indoxacarb in all samples are significantly lower than the MRL value of 0.5 mg/Kg set for tomato by both the Joint FAO/WHO Food Standards Programme [23] and the European Union [24].

The concentrations of metalaxyl during the wet season ranged from <LOQ to 0.02 mg/Kg while concentrations in all samples were <LOQ during the dry season. These concentrations are comparable to those obtained (BDL- 0.105 mg/Kg) in tomatoes grown in Meru County [12] and in Ewaso Narok wetland, Laikipia County [13]. The concentrations were significantly lower than the MRL value of 0.5 mg/Kg set for tomato by the Joint FAO/WHO Food Standards Programme [23] and the 0.3 mg/Kg set by the European Union [24].

Table 2. Concentration of pesticide residues in French beans

Sub-County	Sample	Concentration of analyte (mg/Kg) ; LOQ = 0.01mg/Kg									
		Imidacloprid		Chlorantraniliprole		Spirotetramat		Indoxacarb		Metalaxyl	
		WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
Murang'a East (ME)	071/01	0.07	0.13	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/02	0.09	0.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/03	0.01	0.29	0.37	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/04	0.01	0.25	0.02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/05	0.07	0.26	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/06	0.06	0.19	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Murang'a South (MS)	061/01	0.07	<LOQ	0.23	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	061/02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.02	0.02
	061/03	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	061/04	<LOQ	<LOQ	<LOQ	<LOQ	0.01	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	061/05	<LOQ	<LOQ	0.11	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	061/06	<LOQ	0.04	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Kandara (KAN)	051/01	0.05	0.02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	051/02	0.08	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	051/03	<LOQ	0.03	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	051/04	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	051/05	0.03	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	051/06	<LOQ	<LOQ	0.02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
Thika (TKA)	041/01	<LOQ	0.05	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/03	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/04	<LOQ	<LOQ	<LOQ	<LOQ	0.01	<LOQ	0.05	<LOQ	<LOQ	<LOQ
	041/05	<LOQ	0.04	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/06	<LOQ	<LOQ	0.03	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

Table 3. Concentration of pesticide residues in tomatoes

Sub-County	Sample	Concentration of Analyte (mg/Kg) ; LOQ = 0.01 mg/Kg											
		Profenofos		Omethoate		Chlorantra -niliprole		Spirotetramat		Indoxacarb		Metalaxyl	
		WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
ME	071/01	<LOQ	0.10	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.01	<LOQ
	071/02	<LOQ	0.08	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/03	<LOQ	0.02	<LOQ	0.02	<LOQ	0.08	<LOQ	<LOQ	<LOQ	0.02	<LOQ	<LOQ
	071/04	<LOQ	0.06	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/05	<LOQ	0.18	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	071/06	<LOQ	0.07	<LOQ	<LOQ	<LOQ	<LOQ	0.01	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
MS	061/01	<LOQ	<LOQ	<LOQ	0.02	<LOQ	<LOQ	0.01	<LOQ	<LOQ	0.03	<LOQ	<LOQ
	061/02	<LOQ	0.01	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.02	<LOQ
	061/03	<LOQ	<LOQ	<LOQ	0.02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.02	<LOQ	<LOQ
	061/04	<LOQ	0.02	<LOQ	0.01	<LOQ	<LOQ	0.01	<LOQ	<LOQ	0.02	<LOQ	<LOQ
	061/05	<LOQ	<LOQ	<LOQ	0.02	0.11	0.11	<LOQ	<LOQ	<LOQ	0.02	0.01	<LOQ
	061/06	<LOQ	<LOQ	<LOQ	0.01	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.01	<LOQ
KAN	051/01	<LOQ	0.05	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	051/02	<LOQ	<LOQ	<LOQ	0.02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.03	<LOQ	<LOQ
	051/03	<LOQ	<LOQ	<LOQ	0.01	<LOQ	<LOQ	0.01	<LOQ	<LOQ	0.03	<LOQ	<LOQ
	051/04	<LOQ	0.01	<LOQ	0.02	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.05	<LOQ	<LOQ
	051/05	<LOQ	0.01	<LOQ	0.01	<LOQ	<LOQ	0.01	<LOQ	<LOQ	0.03	<LOQ	<LOQ
	051/06	<LOQ	0.08	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TKA	041/01	<LOQ	0.05	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/02	<LOQ	0.01	<LOQ	0.03	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	0.03	<LOQ	<LOQ
	041/03	<LOQ	0.07	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/04	<LOQ	0.07	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/05	<LOQ	0.11	<LOQ	<LOQ	<LOQ	<LOQ	0.01	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	041/06	<LOQ	0.08	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

ME = Murang'a East; MS = Murang'a South; KAN = Kandara; TKA = Thika; WS = Wet Season; DS = Dry Season; LOQ = Limit of Quantification

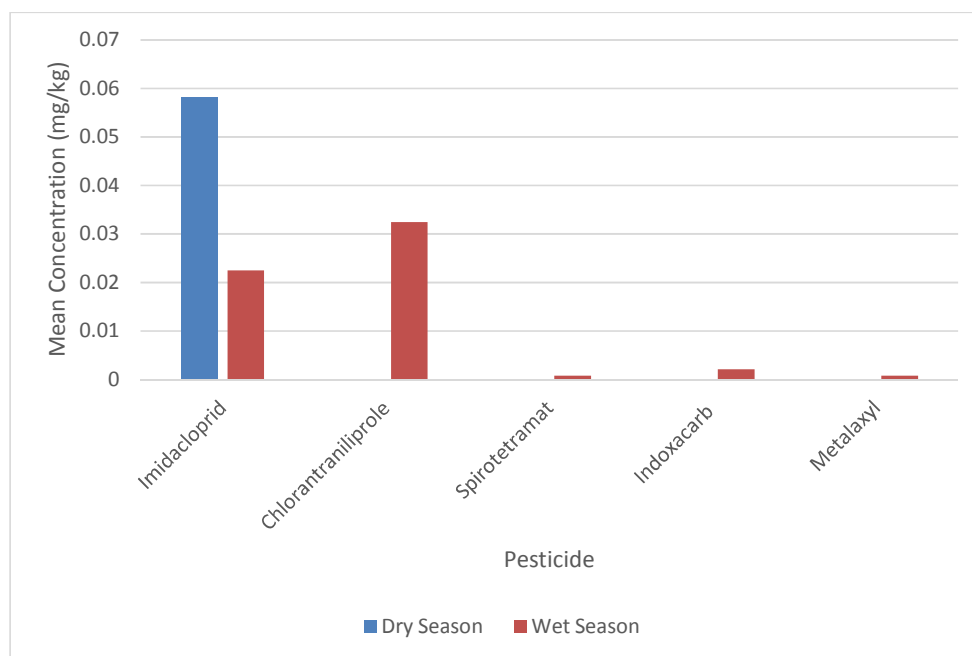


Fig. 2. Mean concentrations of pesticide residues in French beans during the wet and dry seasons

3.4 Seasonal Variation of Pesticide Residues

3.4.1 Seasonal variation of pesticide residue levels in French beans

The mean concentrations of pesticide residues during the wet and the dry seasons are shown in Fig. 2. The mean concentration of imidacloprid were significantly higher during the dry season compared to the wet season. Imidacloprid is a non-volatile, highly soluble systemic insecticide [28]. The rate of hydrolysis of imidacloprid increases with temperature while the rate of penetration through bio-membranes decreases with temperature [28]. The higher concentrations during the dry season can be attributed to higher cuticle permeability of imidacloprid during the warmer season and the washing-off of non-absorbed imidacloprid on the surface of the fruits during the wet season [28].

The concentrations of chlorantraniliprole, spirotetramat, indoxacarb and metalaxyl in French beans were higher during the wet season. The lower concentrations of spirotetramat during the dry season may be due to enhanced hydrolysis during this season. The higher concentrations of chlorantraniliprole and indoxacarb during the wet season may be due to heavier applications during the wet season

presumably due to higher prevalence of insect pests. The higher mean concentration of metalaxyl can be attributed to heavier applications due to higher prevalence of fungal diseases during the wet season.

3.4.2 Seasonal variation of pesticide residues in tomatoes

The mean concentrations of pesticide residues in tomatoes during the wet and the dry seasons are shown in Fig. 3. The mean concentrations of profenofos, omethoate, chlorantraniliprole and indoxacarb residue levels were higher during the dry season compared to the wet season. These insecticides have moderate to high solubility in water and significant vapor pressures at ambient temperatures [29,30,31,32]. The lower concentrations of these insecticides during the wet season can therefore be attributed to several factors including increased surface run-off, degradation through hydrolysis and high partitioning from the vapor phase to suspended particles due to lower temperatures [33,34,35].

The mean concentration of spirotetramat residue was higher during the wet season compared to the dry season. Spirotetramat is a systemic ketoenol insecticide that is practically insoluble (0.03 g/L at 20°C, pH 7) in water and whose hydrolysis increases with temperature [32]. The

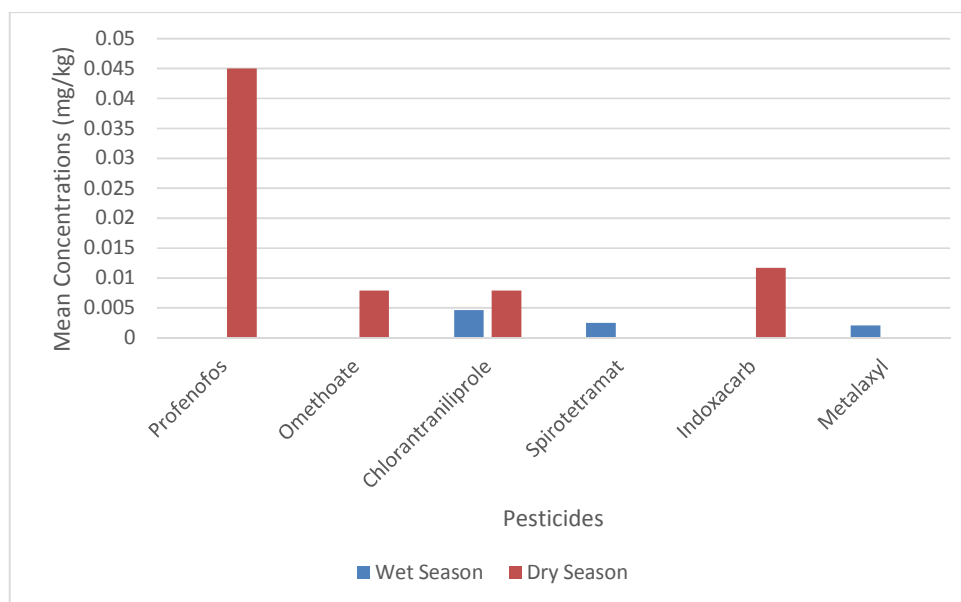


Fig. 3. Mean concentrationsof pesticide residues in tomatoes during the wet and dry seasons

lower mean concentration during the dry season can therefore be attributed to enhanced hydrolysis during this season.

Metalaxyl residue concentrations were higher during the wet season than the dry season. Metalaxyl is a systemic fungicide that is highly soluble in water (8,400 mg/L at 22°C) and has a vapor pressure of 5.62×10^{-6} mm Hg at 25°C [30]. The higher concentrations during the wet season can be attributed to its systemic mode of action and heavier applications due to the higher susceptibility of tomatoes to blights during the wet season.

4. CONCLUSION

Imidacloprid, spirotetramat, chlorantraniliprole, indoxacarb, profenofos and metalaxyl were detected in tomatoes and French beans grown and sold in Murang'a and Kiambu Counties. The concentrations of pesticide residues in the two vegetables were within the MRL levels established by the Joint FAO/WHO Food Standards Programme and the European Union except for omethoate, which had concentrations higher than MRL in 29% of analyzed tomato samples. The concentrations of pesticide residues in tomatoes and French beans obtained from farms and markets in sub-counties were comparable suggesting localized sourcing and consumption. The concentrations of profenofos, omethoate, chlorantraniliprole and indoxacarb

were significantly higher in tomatoes during the dry season compared to the wet season. The lower concentration during the wet season were attributed increased surface runoffs, higher partitioning of residues into the atmosphere and enhanced degradation through hydrolysis during the wet season. The concentrations of metalaxyl and spirotetramat were higher during the wet season than during the dry season. This was attributed to heavier applications during the wet season due to increased prevalence of fungal diseases and pests, respectively. These results calls for a stricter monitoring of pesticide use in tomatoes and French beans, education of farmers on proper pesticide-handling practices and adoption of pesticide-free agro-ecological farming practices to protect consumers against the adverse effects of pesticide residues. Studies should also be conducted to determine the probable dietary exposure and health risks of pesticides residues in tomatoes, French beans and other vegetables in the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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