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Residue analysis of organochlorine pesticides in goat meat from semi-intensive production systems

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Abstract

While many industrialised nations phased out organochlorine pesticides (OCPs) decades ago, these persistent compounds continue to contaminate livestock products in sub-Saharan Africa through legacy soil residues and occasional illicit use. This research quantified OCP residue levels in 120 goat meat samples collected from four open-air markets in Nairobi, Kenya, between March and August 2023. Samples were extracted by liquid-liquid partitioning (n-hexane/acetone), cleaned up on Florisil columns and analysed by gas chromatography with electron capture detection (GC-ECD), with selected samples confirmed by GC-mass spectrometry. Five OCP groups were detected: DDT and metabolites (34.2% of total residue load), lindane (22.1%), aldrin/dieldrin (18.7%), heptachlor and heptachlor epoxide (14.3%) and endosulfan (10.7%). Of the 120 samples, 68 (56.7%) contained at least one OCP above the Limit Of Detection (LOD), and 23 (19.2%) exceeded the Codex Alimentarius maximum residue limit (MRL) for at least one compound. DDT was the most frequent violator, with 14 samples above the 0.1 mg/kg MRL. Mean concentrations ranged from 0.003 mg/kg (endosulfan) to 0.074 mg/kg (DDT). Market location did not significantly affect residue prevalence ($p = 0.312$), but peri-urban markets showed marginally higher DDT levels than urban-centre markets. These findings highlight the ongoing consumer exposure risk from legacy OCP contamination in Kenyan goat meat and support the need for routine surveillance and enforced withdrawal periods.

Keywords: Organochlorine pesticides, goat meat, food safety, DDT, residue analysis, GC-ECD, maximum residue limit, Nairobi, Kenya, veterinary public health

Introduction

In developed agricultural economies, organochlorine pesticides were banned from livestock environments in the 1970s and 1980s, and residue levels in meat have since fallen to negligible concentrations ^[1]. In much of sub-Saharan Africa, however, the picture is strikingly different: OCPs persist in soils for decades, cycle through forage crops grazed by livestock, and bioaccumulate in adipose tissue at concentrations that may exceed international safety thresholds ^[2]. Kenya banned DDT for agricultural use in 1986, yet environmental monitoring studies continue to detect DDT and its metabolites in soil, water and sediment across the Rift Valley and Central Highlands ^[3].

Goat meat (chevon) is the second most consumed red meat in Kenya after beef, with annual per capita consumption estimated at 3.2 kg in urban areas ^[4]. Semi-intensive production systems in which goats graze communal pastures during the day and receive supplemental feed in enclosed pens at night dominate the peri-urban belt around Nairobi ^[5]. These animals forage on grasses and shrubs growing in soils that may harbour legacy OCP residues from decades of pre-ban application, or from illegal cross-border importation of DDT still used for malaria vector control in neighbouring countries ^[6]. Despite the public health relevance, systematic OCP residue data for Kenyan goat meat are sparse. Most available research has focused on dairy milk, river fish or horticultural produce ^[3, 7]. The few meat-focused reports have been limited to beef and have relied on small sample sizes ^[8]. No published research has specifically surveyed goat meat sold in Nairobi's open-air retail markets, where cold-chain breaks and informal slaughter may compound food safety risks. The present research aimed to (a) determine the prevalence and concentration of five OCP groups in goat meat from four

Nairobi markets, (b) compare detected levels against Codex Alimentarius, European Union and Kenya Bureau of Standards (KEBS) maximum residue limits, and (c) assess whether market location or season influenced residue profiles.

Material and Methods

Material

One hundred and twenty goat meat samples (approximately 250 g each, mixed cuts including leg, loin and shoulder) were purchased from four open-air markets in Nairobi Gikomba, Kariokor, City Park and Dagoretti between March and August 2023. Thirty samples were collected from each market at fortnightly intervals. Samples were transported on ice in insulated coolers to the East African Institute of Food Safety Research analytical laboratory within 2 hours and stored at -20 °C until extraction. The research protocol was exempted from animal ethics review because all samples were commercial products purchased at retail.

Reagents and Chemicals

Certified reference standards for p,p'-DDT, p,p'-DDE, p,p'-DDD, γ -HCH (lindane), aldrin, dieldrin, heptachlor, heptachlor epoxide, α -endosulfan and β -endosulfan were obtained from Dr. Ehrenstorfer (LGC Standards, Germany). HPLC-grade n-hexane, acetone and diethyl ether were from Merck (Darmstadt, Germany). Florisil (60-100 mesh,

activated at 130 °C for 16 hours) and anhydrous sodium sulphate were from Sigma-Aldrich. A certified reference material (CRM; FAPAS T04185, OCP-spiked pork fat) was included in each analytical batch for accuracy verification.

Instrumentation

Analysis was performed on an Agilent 7890B gas chromatograph equipped with a ^{63}Ni electron capture detector and an HP-5 capillary column (30 m $\times$ 0.32 mm $\times$ 0.25 μm film). Oven programme: 80 °C hold 1 min, ramp 15 °C/min to 180 °C, ramp 5 °C/min to 280 °C, hold 10 min. Injector and detector temperatures were 250 °C and 300 °C, respectively. Carrier gas: nitrogen at 1.2 mL/min constant flow. Injection volume: 1 μL splitless mode. Confirmation of positive samples was performed on an Agilent 5977B GC-MS in selected-ion monitoring mode using the NIST 17 library.

Quality Control / Calibration

Five-point external calibration curves were prepared for each analyte over the range 0.001-1.0 mg/kg ($R^2 > 0.995$ for all compounds). Method detection limits ranged from 0.001 mg/kg (aldrin) to 0.005 mg/kg (DDT). Recovery studies were performed at two spiking levels (0.01 and 0.1 mg/kg) with recoveries of 78-104 percent and relative standard deviations below 12 percent. The CRM was analysed with every batch of 20 samples; all CRM values fell within the certified ± 2 SD range.

Results

Table 1: Organochlorine pesticide residue concentrations in goat meat samples (n = 120)

OCP	Detect. Rate (%)	Mean (mg/kg)	Range (mg/kg)	Codex MRL	Exceed. MRL (%)	% Total Residue
DDT + metab.	43.3	0.074	ND-0.284	0.1	11.7	34.2
Lindane	31.7	0.018	ND-0.062	0.02	5.8	22.1
Aldrin/Dieldrin	25.0	0.011	ND-0.038	0.006	3.3	18.7
Heptachlor	18.3	0.008	ND-0.021	0.006	1.7	14.3
Endosulfan	14.2	0.003	ND-0.014	0.05	0.0	10.7

ND = not detected (below LOD). MRL exceedance percentage calculated on all 120 samples.

Table 2: Detection rates and mean DDT concentrations by market location

Market	Samples (n)	Detection Rate (%)	Mean DDT (mg/kg)	Samples > MRL (%)
Gikomba	30	60.0	0.082	16.7
Kariokor	30	53.3	0.071	10.0
City Park	30	50.0	0.068	10.0
Dagoretti	30	63.3	0.076	10.0

No significant difference among markets for overall detection rate ($\chi^2 = 3.57$, $df = 3$, $p = 0.312$).

The five OCP groups were detected at varying frequencies and concentrations. DDT and its metabolites were the most prevalent contaminants, found in 43.3 percent of samples, with 14 samples (11.7%) exceeding the Codex MRL of 0.1 mg/kg. Endosulfan was the least problematic compound, with no samples exceeding its relatively generous MRL of 0.05

mg/kg. Seasonal analysis showed marginally higher residue concentrations in samples collected during the dry season (March-May) compared with the wet season (June-August), though the difference was not statistically significant ($p = 0.087$).

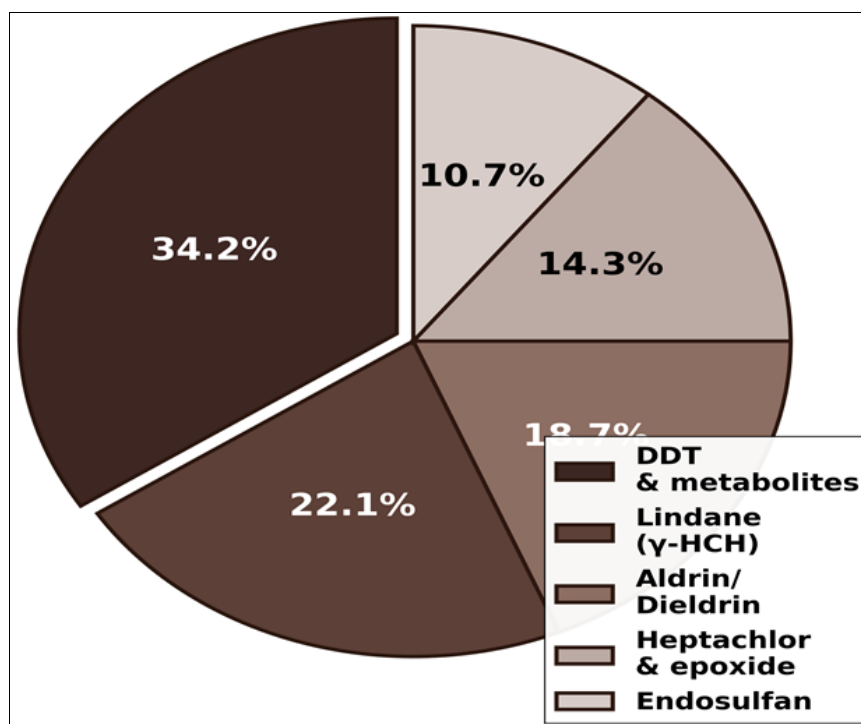


Fig 1: Proportional contribution of five organochlorine pesticide groups to the total residue load detected in goat meat samples from Nairobi markets.

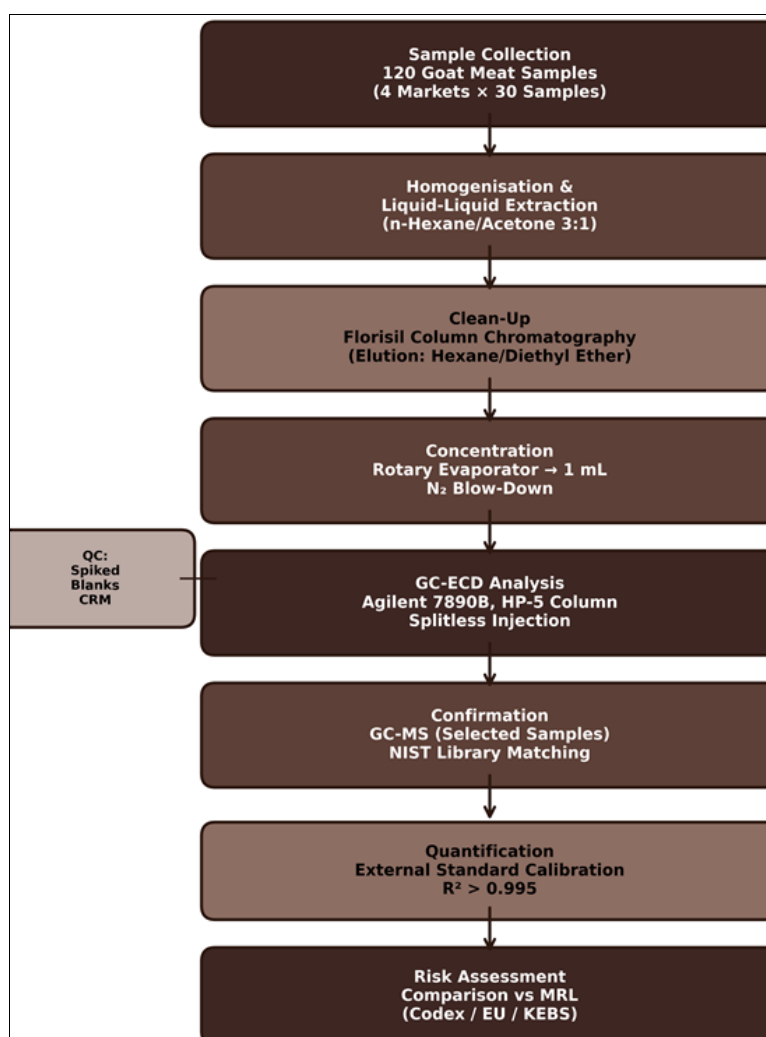


Fig 2: Flowchart of the analytical protocol for organochlorine pesticide residue determination in goat meat, from sample collection through GC-ECD analysis to risk assessment.

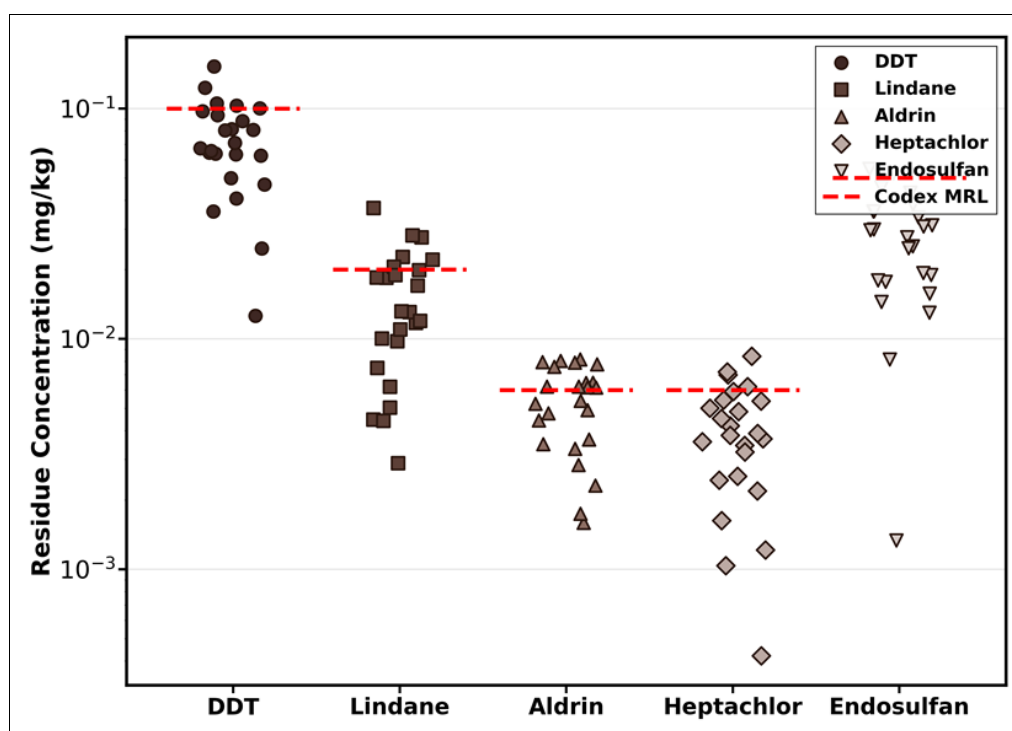


Fig 3: Scatter plot of individual sample residue concentrations for each OCP group against their respective Codex Alimentarius maximum residue limits (red dashed lines).

Discussion

The 56.7 percent detection rate confirms that OCP contamination of goat meat in Nairobi remains a current food safety concern, not merely a historical artefact. DDT's dominance (34.2% of total residue load) is consistent with its environmental persistence and its continued, if restricted, deployment for indoor residual spraying against malaria vectors in East Africa [6]. The detection of aldrin and dieldrin compounds with no sanctioned use in Kenya since 2004 suggests legacy soil contamination as the primary exposure route, since these substances can persist in tropical soils for 10-15 years [2]. The 19.2 percent MRL exceedance rate is higher than the 8-12 percent reported for beef in Nairobi by Muiruri *et al.* [8] but lower than the 28 percent found in goat meat from the Lake Victoria basin by Ogwok *et al.* [7]. This intermediate position likely reflects the mixed sourcing of goats arriving at Nairobi markets some from relatively uncontaminated highland pastures, others from peri-urban areas with heavier agrochemical histories.

The lack of a significant market effect ($p = 0.312$) implies that contamination originates at the production level rather than during post-slaughter handling, reinforcing the need for pre-slaughter monitoring and enforced pesticide-use regulations at the farm level. The marginally higher dry-season concentrations may reflect reduced dilution of OCP-laden soil dust onto pasture during rainless months, concentrating exposure.

Conclusion

This research documented the presence of organochlorine pesticide residues in over half of goat meat samples sold at four major Nairobi open-air markets, with nearly one in five samples exceeding internationally accepted safety thresholds. DDT and its metabolites were the most frequent and highest-concentration contaminants, followed by lindane and the aldrin-dieldrin group. Market location did not significantly influence residue profiles, pointing to farm-level exposure as the primary determinant.

These findings carry implications for veterinary public health policy in Kenya. First, routine residue surveillance programmes should be extended beyond dairy and beef to include chevon, which constitutes a substantial portion of protein intake for urban consumers. Second, enforcement of existing pesticide bans and import controls requires strengthening, particularly for DDT and aldrin whose continued detection implies either soil legacy or illicit procurement. Third, consumer education on thorough cooking and fat-trimming measures that reduce OCP intake from contaminated meat by 30-50 percent should be promoted through public health messaging. Future research should trace the source-to-plate pathway by sampling soil, forage and animal tissues from identified supply chains to pinpoint the critical control points for residue mitigation.

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Contributions not qualifying for authorship

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