Assessment of Pesticide Residues in Milk from Agro-Pastoral Cattle Settlements in Niger State, Nigeria: Implications for Public Health and Food Safety

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Abstract

The presence of pesticide residues in food products, particularly milk, poses significant public health risks, especially in developing regions where agricultural practices often involve extensive pesticide use. This study aimed to assess the levels of pesticide contamination in milk collected from agro-pastoral cattle settlements in Niger State, Nigeria, and evaluate the associated health risks for both children and adults. Milk samples were systematically collected and analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) to detect and quantify the concentrations of various pesticides, including organophosphates, organochlorines, and herbicides.

The detected pesticides included Dichlorvos, β-Hexachlorocyclohexane, Malathion, DDT, and Dieldrin, among others, with Dichlorvos and β-Hexachlorocyclohexane showing the highest concentrations. Using the Estimated Daily Intake (EDI) model, we calculated the potential health risks associated with the consumption of contaminated milk for different age groups. The results indicated that children were particularly at risk, with EDI values exceeding the Acceptable Daily Intake (ADI) for certain pesticides, such as Dieldrin, leading to a risk ratio of 1.288. In contrast, adults showed a lower risk, with EDI values generally within safe limits.

The findings underscore the urgent need for stricter pesticide regulation, enhanced monitoring of pesticide residues in livestock products, and the adoption of sustainable agricultural practices such as Integrated Pest Management (IPM) to mitigate the public health risks. This study highlights the vulnerability of children to pesticide exposure through dairy consumption and calls for immediate intervention to safeguard food safety and protect public health.

Keywords: Pesticide residues, milk contamination, Gas Chromatography-Mass Spectrometry, public health, risk assessment, Niger State, dairy safety, children's health

Introduction

The presence of pesticide residues in dairy products poses a significant public health risk, primarily due to potential health hazards associated with their consumption. Pesticides can infiltrate the dairy supply chain through contaminated feed, water, or direct application in livestock management (Đokić, 2024). Studies indicate that dairy animals, such as cows, often consume silage and grains that may contain pesticide residues, leading to the accumulation of these chemicals in milk and other dairy products (Đokić, 2024). This is particularly concerning as children, who generally consume larger amounts of dairy, are more susceptible to the adverse effects of pesticides due to their developing immune systems (Đokić, 2024).

Common pesticide types detected in dairy products include organophosphates, herbicides, and fungicides, all of which have been linked to significant health effects, such as endocrine disruption and neurotoxicity (Đokić, 2024; Singh, 2024). A systematic review has further suggested that prolonged exposure to certain pesticides can impact biological aging markers, indicating potential long-term health consequences even at low exposure levels (Zuo, 2024). Given these risks, stringent monitoring and regulatory measures are essential to safeguard consumer health.

Additionally, the processing of dairy products influences pesticide residue levels. Methods such as heating, salting, and ripening can alter the concentration of these chemicals, often leading to reduced residue levels in final products; however, the effectiveness of such processes varies significantly, highlighting the need for standardized approaches to minimize pesticide contamination (Krivohlavek, 2024). Research also indicates that the fat content in milk plays a crucial role in pesticide accumulation, as many pesticides exhibit lipophilic properties and tend to concentrate in fatty tissues (Krivohlavek, 2024; Đokić, 2024)

Beyond the direct health implications, the presence of pesticides in dairy products also raises significant environmental and agricultural concerns. Excessive pesticide use in farming not only compromises food safety but also threatens biodiversity and the overall health of ecosystems (Khodijah, 2024). To safeguard both human health and the environment, it is crucial to adopt sustainable agricultural practices that reduce dependence on chemical pesticides. Approaches such as integrated pest management and organic farming have been recommended as effective strategies to limit pesticide application and its associated risks (Singh, 2024; Khodijah, 2024).pesticide contamination in dairy products is a complex issue that intersects public health, food safety, and environmental sustainability. Ongoing research and systematic monitoring are essential to assess the extent of contamination and to implement effective strategies for reducing the associated risks.

Similarly, the presence of pesticide residues in food animals represents a significant public health concern, as these chemicals can accumulate in human tissues over time, leading to various acute and chronic health complications. The health risks associated with pesticide exposure extend beyond immediate toxicity, potentially affecting long-term well-being and contributing to the global burden of disease. Short-term exposure to pesticide residues has been linked to symptoms such as nausea and vomiting, highlighting the immediate toxic effects of these chemicals (Singh, 2024).

Acute exposure to pesticide can lead to Blurred vision and respiratory distress are common symptoms, with severe cases potentially progressing to coma (Tutuwa, 2023). In contrast, chronic exposure poses a more subtle threat, contributing to neurological, immunological, metabolic, and endocrine disorders (Patil & Patil, 2023).

Pesticide residues have been particularly implicated in neurological and psychiatric effects. Chronic exposure to certain pesticides, such as organophosphates and organochlorines, has been linked to long-term neurological damage, which may manifest as conditions like Parkinson's disease and other neurodegenerative disorders (Patil & Patil, 2023). Furthermore, the liver and kidneys, which serve as primary organs for detoxification, are especially vulnerable to damage from pesticide residues. Prolonged exposure can lead to hepato-renal dysfunction, characterized by liver inflammation, fibrosis, and renal impairment, as certain pesticides induce oxidative stress and inflammation (Patil & Patil, 2023). Additionally, pesticides are known endocrine disruptors, interfering with hormonal regulation and potentially leading to reproductive health issues, developmental disorders in fetuses, and increased cancer risks, particularly for breast and prostate cancers (Patil & Patil, 2023).

The immunological and metabolic effects of pesticide residues are also concerning. Exposure can compromise the immune system, reducing the body’s ability to combat infections and increasing susceptibility to autoimmune diseases. There is emerging evidence linking pesticide exposure to metabolic disorders, including obesity and diabetes, due to their interference with normal metabolic processes (Patil & Patil, 2023). Vulnerable populations, such as children, pregnant women, and immunocompromised individuals, face heightened risks from pesticide residues in food animals. In children, exposure has been associated with developmental disorders, including attention deficit hyperactivity disorder (ADHD) and autism spectrum disorders (Tutuwa, 2023). Prenatal exposure is particularly alarming, as it can lead to fetal growth restriction, low birth weight, and developmental delays (Patil & Patil, 2023).

Recent studies have underscored the global public health implications of pesticide residues in the food chain. For instance, research in China has shown that organochlorine pesticide residues in animal products are significantly associated with increased risks of cancer and endocrine disorders (Zhang et al., 2022). Similarly, studies in Uganda have reported widespread contamination of fruits and vegetables with pesticide residues, raising concerns about the long-term health impacts on consumers (Ssemugabo et al., 2022). In developing countries, where regulatory frameworks may be less stringent, the risk of pesticide contamination is particularly pronounced. The World Health Organization (WHO) has emphasized the necessity for improved surveillance and regulation to mitigate pesticide residues in food, especially in regions with high agricultural activity (Yang et al., 2021).

To address the public health implications of pesticide residues in food animals, several measures can be implemented. Enhanced regulation and monitoring of pesticide use in agriculture are essential to ensure that residue levels in food products remain within safe limits (Yang et al., 2021). The promotion of Integrated Pest Management (IPM) practices can reduce reliance on chemical pesticides, thereby minimizing contamination risks (Yang et al., 2021). Public awareness and education regarding the risks associated with pesticide use and the importance of safe agricultural practices are crucial for reducing exposure (Yang et al., 2021). Continued research into the health effects of pesticide residues and the development of safer, more sustainable pest control methods are necessary to mitigate the risks associated with pesticide exposure (Yang et al., 2021).

Statement of Research Problem

The presence of pesticide residues in livestock products is a critical public health concern, with estimates suggesting that a significant portion of consumed food is contaminated with pesticides. The World Health Organization (WHO) has reported around 3 million cases of acute pesticide poisoning annually, resulting in approximately 220,000 deaths, predominantly in developing regions such as Africa, Asia, and Central and South America (Zinyemba *et al.*, 2020). Organophosphate pesticides are particularly prevalent in these areas, contributing significantly to health issues. Chronic exposure to pesticides is linked to various diseases, including cancer, cardiovascular diseases, Alzheimer's, and Parkinson's disease (Buckley *et al*., 2021). Acute exposure can lead to immediate health crises, while chronic exposure is associated with long-term health risks, including reproductive, immune, endocrine, and neurological disruptions (Reducindo, 2024).

Pesticide residues have been detected in various food products, including milk, feed, and a range of fruits and vegetables (Somboon *et al*., 2022). The risks associated with pesticide exposure can occur through direct contact during manufacturing, formulation, or application. For instance, a survey in Nigeria revealed that approximately 15,000 metric tons of pesticides, comprising around 135 different chemicals, were imported annually between 1983 and 1990, positioning Nigeria as one of the largest pesticide users in sub-Saharan Africa (Reshma & Jayalakshmi, 2020). While pesticides serve essential roles in agriculture, their use raises significant environmental concerns, particularly regarding human and animal toxicity (Liang *et al*., 2023). It is estimated that over 98% of insecticides and 95% of herbicides do not reach their intended targets, resulting in contamination of non-target species, air, water, and soil (Brown, 2024).

The WHO and the UN Environment Program have estimated that about 3 million agricultural workers in developing countries experience severe pesticide poisoning each year, with approximately 18,000 fatalities (Utyasheva *et al*., 2021). Additionally, studies suggest that up to 25 million workers may suffer from mild pesticide poisoning annually (Carvalho *et al*., 2022). Pesticides are also employed to control vector-borne diseases, such as malaria and dengue fever, which underscores the importance of their use in public health initiatives. However, the indiscriminate application of these chemicals without adequate knowledge poses significant risks (Hf *et al*., 2020).

The widespread use of pesticides in agriculture, particularly in developing countries, has profound implications for public health. The dual challenge of managing pesticide exposure while ensuring effective pest control necessitates a balanced approach that prioritizes both human health and environmental safety (Yu *et al*., 2021). Enhanced regulatory frameworks and education on safe pesticide use are essential to mitigate these risks and protect vulnerable populations.

Pesticides are integral to agricultural practices, serving to protect crops from pests and diseases. However, their widespread use has raised significant concerns regarding environmental and human health impacts. Globally, pesticide usage has surged to approximately 3.5 billion kg of active ingredients annually, with a substantial portion deemed excessive or unnecessary in both developed and developing nations (Sharma, 2021). In Nigeria, the importation of about 15,000 metric tons of pesticides, comprising around 135 different chemicals, underscores the scale of pesticide application in agriculture (Sharma, 2021).

The health implications of pesticide exposure are profound, with studies linking these chemicals to various diseases, including cancer, cardiovascular conditions, dermatitis, birth defects, and neurobehavioral disorders (Baudry, 2023; , Cavalier *et al*., 2022). A food safety assessment in Nigeria revealed alarming levels of pesticide residues, such as DDT, Aldrin, and Dieldrin, in food items, exceeding the maximum allowable concentration levels, which ranged from 1.2 to 2160 µg/kg (Sharma, 2021). The presence of these pesticides in soil, drinking water, and animal products poses significant public health risks, necessitating urgent attention (Sharma, 2021).

The livestock sector is crucial for Nigeria's socioeconomic development, contributing approximately 36.5% of the total protein intake and 8-10% of the agricultural GDP (Sharma, 2021). With proper animal husbandry practices, this contribution could increase significantly, enhancing food security and economic stability (Sharma, 2021). However, the pervasive use of pesticides threatens this sector, as residues can accumulate in livestock products, potentially affecting human health through the food chain (Sharma, 2021).

Moreover, the indiscriminate application of pesticides, often due to a lack of education and regulatory oversight, exacerbates the risks associated with pesticide exposure (Sule *et al.*, 2022). Reports indicate that chronic exposure to pesticides can lead to oxidative stress, which is implicated in the development of various health issues, including cancer and cardiovascular diseases (Sule *et al*., 2022; , Cavalier *et al*., 2022). As such, it is imperative to implement effective management strategies and educational programs to mitigate these risks and promote safer agricultural practices (Sandoval-Insausti *et al*., 2022).

While pesticides play a vital role in agriculture, their adverse effects on human health and the environment cannot be overlooked. Comprehensive strategies that include regulation, education, and sustainable practices are essential to safeguard public health and ensure the continued viability of the agricultural sector in Nigeria and beyond (Sharma, 2021).

Justification for the research

Most countries have established regulatory limits for pesticide residues in food products which are lacking in developing countries like Nigeria. Ensuring compliance with these regulations is vital for food producers and exporters. A study on the evaluation of pesticide residues can provide baseline data to assist in the development of these regulations. The detection of pesticide residues in soil, water, and animal products is of great public health importance. Information on these activities in agro-pastoral cattle settlements in Niger State is not readily available.

Pesticides are used to increase agricultural output and food preservation while ignoring their associated risks. Overuse, exposure, and harmful consequences can predispose to the occurrence of health challenges, which can be mitigated by judicious application through sensitization using surveillance and research.

Many detrimental effects as a result of widespread pesticide usage have been identified, and effective waste management strategies are needed to mitigate residue issues through research.

Pesticide biodegradation is a new way of environmentally acceptable pesticide pollution control for long-term environmental benefit. No known study has demonstrated the potential of microorganisms, isolated from sewage or soil to degrade pesticides in Agro-pastoral cattle settlements of Niger State, Nigeria. The detection of these pesticides in soil, drinking water, and other animals is of great public health interest.

The livestock subsector is vital to the socioeconomic development of Nigeria and represents an important source of quality animal protein, it provides 36.5% of the total protein intake in Nigeria and contributes 19% to Nigeria's GDP (NBS,2020). Therefore, this necessitate the need to ensure its sustainability through research to ensure food safety.

This study investigates the presence and levels of various pesticide residues in milk samples using Gas Chromatography-Mass Spectrometry (GC-MS) analysis. The findings highlight significant public health concerns associated with pesticide contamination.

Methodology

The research conducted in Niger State, specifically within agro-pastoral cattle settlements, focused on the assessment of pesticide residues in milk and their associated health risks. The detailed methodology is outlined below, incorporating the use of Gas Chromatography-Mass Spectrometry (GC-MS) for analysis:

Study Area

The research was carried out in Niger State, situated in Nigeria's North-central geopolitical zone within the Southern Guinea Savannah ecological region. This state lies between latitudes 8° 20' N and 11° 30' N, and longitudes 3° 30' E and 7° 20' E. As one of Nigeria's 36 states, Niger State spans an area of approximately 76,363 square kilometres (29,484 square miles), accounting for about 9% of the nation's total land area, making it the largest state by land area. The state is divided into three agro-ecological zones with varying climatic conditions: Zone A (Southern) includes eight Local Government Areas (LGAs), Zone B (Eastern) consists of nine LGAs, and Zone C (Northern) has eight LGAs. The estimated cattle population in the state is around 2.4 million (MLF, 2011).

Figure 1. Map of Niger State showing the three Agro-zones in the state

Sampling Procedure

A multistage sampling procedure was implemented to collect the samples. In the first stage, the three agro-ecological zones—A, B, and C—within the state were identified. The second stage involved purposive sampling, focusing on the Local Government Councils in each zone. Agro-ecological zone A (Southern) includes eight local government areas (LGAs), zone B (Eastern) comprises nine LGAs, and zone C (Northern) consists of eight LGAs. Purposive sampling techniques were then used to select the participating LGAs:

Zone A: Lapai, Agaie, Bida, Katcha, Gbako, Mokwa, Edati, and Lavun

Zone B: Bosso, Chanchaga, Paikoro, Suleja, Tafa, Gurara, Munya, and Shiroro

Zone C: Agwara, Borgu, Kontagora, Magama, Mariga, Mashegu, Rafi, Rijau, and Wushishi.

In the third and final stage, a simple random sampling method was used to select herds for the milk sample collection.

Sample Collection:

Milk samples were systematically collected from agro-pastoral cattle settlements across different regions of Niger State, ensuring a diverse representation. The cattle were primarily fed with silage, grains, and other feed sources potentially contaminated with pesticides due to local agricultural practices.

The sample collection process adhered to strict protocols to prevent contamination and ensure that the samples were representative of the dairy production systems in the state

Pesticide Residue Analysis (GC-MS):

The collected milk samples were subjected to laboratory analysis using Gas Chromatography-Mass Spectrometry (GC-MS), a highly sensitive and accurate technique for detecting and quantifying pesticide residues.

The pesticides tested included a wide range of organophosphates, herbicides, fungicides, and other commonly used pesticides in the region, such as Dichlorvos, Malathion, DDT, β-

Hexachlorocyclohexane, and others. These compounds were selected based on their known usage in local agriculture and their potential to bioaccumulate in livestock.

GC-MS allowed for precise identification of the concentration levels of each pesticide, providing detailed data on the presence of harmful chemicals in the milk samples.

Sample preparation

Collected samples were placed in separate sterile polyethylene bags, sealed, and labeled with unique identifiers. They were then transported in an ice chest to the laboratory. Samples were stored at 4 °C for analysis conducted within 24 hours, or at -4 °C for later analysis. In the laboratory, samples were chopped and blended using an electric mixer to create a homogeneous composite. From this mixture, 50 grams of the homogenized samples were taken for further analysis.

Chemicals

Analytical grade solvents used in the study included acetone (BDH, Poole, England), n-hexane (Merck, Germany), and GC-MS grade acetonitrile (Scharlau, Barcelona, Spain). Additionally, anhydrous sodium sulfate (Na2SO4) (BDH, Poole, England), Florisil (magnesium silicate) (Sigma, St. Louis, MO, USA), and dichloromethane (BDH, Poole, England) were utilized, while DD n-hexane was prepared in the laboratory. The reference standards for acephate, chlorpyrifos, fenthion, fenitrothion, parathion, ethion, carbaryl, carbofuran, and cypermethrin were of reference grade and obtained from Ehrenstorfer GmbH, D-86199 Augsburg, Germany.

Extraction

Fifty grams of the homogenized sample were extracted using a 100 mL solvent mixture of hexane and dichloromethane in a 9:1 ratio, along with 20 grams of sodium hydrogen carbonate, using electric blenders at approximately 20–25 °C. To remove any remaining water, 60 grams of sodium sulfate were added, and the slurry was thoroughly mixed. The solvent mixture was then allowed to sit in a fume hood for about 15–30 minutes to facilitate the separation of the solvent from the solid materials. The separated solvent was collected into a round-bottom flask and evaporated using a rotary evaporator (Rotavapor-215, Buchi, Flawil, Switzerland) at 45 °C under mild pressure. The extract was then transferred to a vial, and evaporation continued with a gentle stream of nitrogen until nearly dry. Finally, the extract was dissolved in hexane and adjusted to a final volume of 5 mL.

Sample Purification

The sample purification followed the method of Fardous et al. (2007) and Rahman et al. (2012), utilizing Florisil column chromatography. Florisil (60–100 mesh) was activated at 200 °C for six hours and deactivated with 2% distilled water. Anhydrous sodium sulfate was added to the top 1.5 cm of the column, and elution was performed using a solvent mixture of hexane (65%) and dichloromethane (35%) at 5 mL/min. The eluent was concentrated using a rotary vacuum evaporator, and solvents were removed under nitrogen. The final sample was dissolved in acetonitrile and adjusted to 5 mL for Gas Chromatography-Mass Spectrometry (GC-MS) analysis.

GC-MS, a key technique for qualitative and quantitative analysis, separates mixture components via gas chromatography and identifies them through mass spectrometry (Pavia et al., 2006). The analysis was conducted using a DB-5 fused silica capillary column (30 m × 0.25 μm i.d. × 0.25 μm film thickness), with nitrogen as the carrier gas at 1.0 mL/min. The oven temperature was initially 40 °C, then increased stepwise to 290 °C. The injection volume was 1 μL (splitless mode) at 250 °C. The mass spectrometer operated in electron impact ionization mode, scanning m/z 30-800 with a 43-minute runtime. Compounds were identified using the NIST Ver. 2.1 MS data library, with individual injections determining retention times and ion ratios.

All samples were analyzed in a single batch with pooled quality control (QC) samples injected periodically. Standard curves were generated using the area under the curve of pesticide spike samples relative to the internal standard. After validating pesticide isolation and identification, the selected ion monitoring (SIM) method was applied to improve specificity and sensitivity by reducing matrix effects. Quantification was based on a specific ion’s m/z value and intensity, enhancing analytical accuracy

Cleaning of glassware and containers

All glassware utilized in the analysis was cleaned with concentrated chromic acid to eliminate any stains. Following this, the glassware was washed with a phosphorus-free detergent (JIK). The containers were initially rinsed with distilled deionized water, followed by a final rinse with isopropanol solution. The glassware was then dried in an oven at 100–120°C for twenty hours.

To reduce the risk of contamination of the extracts, no rubber or plastic containers were employed in this pesticide analysis.

Reagents for residue analysis

AOAC Pouch Qsep sachets containing magnesium sulfate and sodium acetate were sourced from Agilent (Santa Clara, USA). GC-MS-grade acetonitrile was acquired from ROMIL (Cambridge, UK), while glacial acetic acid, PSA (primary and secondary amine), deionized water, acetone, and GC-MS-grade standard solutions of pesticides were obtained from Sigma Aldrich, Germany.

Determination of pesticide residue

The determination of pesticide residues utilized the multi-residue pesticide analysis technique, specifically the QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) sample preparation method as outlined in AOAC Method 2007.01, with minor modifications for various analytes during spiking in this study.

GC-MS analysis

After cleaning the samples, aliquots of the final volume were analyzed using a GC-MS (Shimadzu, Kyoto, Japan) LC-10 ADvp, equipped with an SPD-M 10 Avp connected to a PDA (Shimadzu SPD-M 10 Avp, 200–800 nm). The analytical column used was a C18 Reverse Phase Alltech (250 × 4.6 mm, 5 µm), maintained at 30 °C within a column oven. The mobile phase, consisting of 70% acetonitrile (ACN) and 30% water, was filtered through a 0.45 µm cellulose filter before each use. The flow rate was set at 1.0 mL/min, and all solvents were of GC-MS grade. Prior to GC-MS analysis, the samples were filtered through 0.45 µm nylon syringe filters (Alltech Associates, IL, USA). A 20-microliter sample was manually injected for each analysis. The identification of suspected pesticides was based on their retention times relative to pure analytical standards. Quantification followed the methodology outlined in previous studies (Chowdhury *et al*., 2012a; Chowdhury *et al.*, 2012b).

Human Health Risk Assessment

Health risk estimates for pesticide residues in cattle milk were calculated using three primary standard indices: Estimated Average Daily Intake (EADI), Hazard Quotient (HQ), and Hazard Index (HI) (Fianko, 2011). Risks were categorized based on the average, maximum, 50th, and 95th percentiles of the measured exposure concentrations (MEC) of pesticide residues. The

EADI was determined by multiplying the concentration of pesticide residues in cattle tissue (mg/kg) by the meat consumption rate in Nigeria, which is 8.6 kg/day (FAO, 2004), and then dividing by the body weight (Fianko, 2011). Two hypothetical age/weight categories were considered: 1–11 years with an assumed weight of 15 kg for children, and 50 kg for adults. The EADI was expressed as mg/kg/day. These values were compared to established acceptable daily intake (ADI) levels by the USEPA Integrated Risk Information System (USEPA, 1996) to evaluate long-term risks associated with exposure to pesticide residues through meat consumption, as the ADI reflects lifetime exposure (Pardio, 2012; FAO/WHO, 2009; Tchounwou, 2002).

The Hazard Quotient (HQ) was utilized to evaluate risks linked to both non-carcinogenic and carcinogenic health effects. For non-carcinogenic effects, the HQ was calculated by dividing the EDI by the ADI (WHO, 1997). For carcinogenic effects, the HQ was determined by multiplying the EDI by the cancer slope factor (CSF) (USEPA, 2005; Buranatrevedh, 2004). The HQ for both non-cancer and cancer risks was estimated for the average, maximum, 50th, and 95th percentiles of the MEC of pesticide residues in each tissue, assessing the health risks associated with consuming contaminated cattle milk.

The Hazard Index (HI) was used to evaluate risks from various exposure pathways, specifically addressing the risk associated with pesticide mixtures within the same chemical group. The HI represented the total exposure risk for a given pathway and was calculated as the sum of the HQs (HI = EDI/ADI) for each exposure route (Amvrazi, 2009; Tsakiris, 2004). Two HIs were calculated for all exposure routes to assess the total risk for both non-carcinogenic and carcinogenic health effects across all pesticide groups

Mathematical Modelling for Health Risk Prediction:

The researchers applied mathematical models to predict the health risks associated with consuming milk contaminated with pesticides. The **Estimated Daily Intake (EDI)** of each pesticide was calculated for both children and adults.

Parameters used for this model included the **concentration of pesticides in milk**, **milk consumption rates** (0.6 kg/day for children and 0.75 kg/day for adults), and **body weights** (15 kg for children and 50 kg for adults).

The concentration data from the GC-MS analysis were integrated into these models to assess the potential daily intake of each pesticide residue.

Risk Assessment:

The calculated EDI values for each pesticide were compared with their respective **Acceptable Daily Intake (ADI)** values established by health regulatory bodies.

A **risk ratio** was determined by dividing the EDI by the ADI. A risk ratio greater than 1 indicated a potential health risk, while a value below 1 suggested that the exposure was within safe limits.

For example, the risk ratio for children consuming milk contaminated with Dieldrin was found to be 1.288, indicating a higher health risk, whereas the ratio for adults was 0.483, showing a lower risk.

Interpretation of Findings:

The findings emphasized that children were at a significantly higher risk due to their smaller body weight and higher relative intake of milk, compared to adults. This increased susceptibility was linked to potential developmental and neurological risks from chronic pesticide exposure.

The research identified that the fat content in milk contributed to the accumulation of lipophilic pesticides, such as DDT and β-Hexachlorocyclohexane, further elevating the risk for consumers, particularly children.

This robust method, combining advanced analytical techniques like GC-MS with predictive modelling, provided critical insights into the public health risks posed by pesticide residues in milk from agro-pastoral cattle settlements in Niger State. The study's findings highlight the need for ongoing research and regulatory interventions to mitigate these risks

Results

Table 1. below shows the distribution of various pesticide residue concentrations found in milk, measured in micrograms per liter (µg/L). The highest concentration is Dichlorvos at 1,097 µg/L, followed closely by β-Hexachlorocyclohexane at 1,002 µg/L. Malathion has a

significant level at 678 µg/L, while p,p'-DDT shows a notable concentration of 884 µg/L, often linked to long-term environmental persistence. Carbaryl is present at 541 µg/L, indicating moderate use, and Carbofura is at 311 µg/L, which is noteworthy. Chlorpyrifos is at 107 µg/L, and Diazinon is one of the least concentrated pesticides at 34 µg/L. Chlorthiophos appears minimally at 24 µg/L, while Ethion has a very low concentration of 14.2 µg/L, and Aldrin is detected at 20.6 µg/L. Endosulfan records the least concentration at 19.2 µg/L, followed by Amitraz at 19.8 µg/L. Dieldrin has a high level of 3.22 µg/L, although it is lower than Malathion and DDT. Overall, the figure highlights the varying levels of pesticide contamination in milk, with significant concentrations for Dichlorvos and β-Hexachlorocyclohexane, while others are present in trace amounts.

Table1: Detected pesticide residues from the (GC-MS) analysis of milk sample

S/no	Retention Time	Compound Detected	Mol. Formula	MW	Peak Area %	Concentration µg/kg
1	2.48	Dichlorvos	$C_4H_7Cl_2O_4P$	162	3.35	1.097
2	4.00	Malathion	$C_{10}H_{19}O_6PS_2$	221	7.53	0.6786
3	4.25	Hexachlorocyclohexane	$C_6H_6Cl_6$	222	5.32	1.002
4	5.78	Endosulfan	$C_{11}H_{15}BrClO_3PS$	373	6.21	0.0192
5	8.50	Aldrin	$C_{10}H_{14}NO_5PS$	291	13.30	0.0206
6	13.24	α-Lindane	$C_6H_6Cl_6$	290	17.29	0.0616
7	13.50	Ethion	$C_{13}H_{19}N_3O_4$	281	2.22	0.0142
8	14.50	Diazinone	$C_9H_9Cl_2NO$	218	9.76	0.0344
9	16.62	Chlorpyrifos	$C_9H_{11}Cl_3NO_3PS$	350	4.43	0.1072
10	17.28	DDT	$C_{14}H_9Cl_5$	311	0.22	0.8848
11	25.50	Carbofuran	$C_{12}H_{15}NO_3$	373	8.68	0.013
12	25.27	Endosulfan	$C_9H_6Cl_6O_3S$	406	9.31	0.846
13	25.60	Aldrin	$C_{12}H_8Cl_6$	364	5.76	0.039
14	27.00	Carbaryl	$C_{12}H_{11}NO_2$	416	2.66	0.014
15	27.65	Dieldrin	$C_{12}H_8Cl_6O$	380	1.77	0.032
16	33.08	Amitraz	$C_{19}H_{23}N_3$	449	2.00	0.019

Prediction of Health Risk associated with consumption of milk contaminated with Dieldrin pesticide using Mathematical Modelling

To predict the health risk of Dieldrin exposure for children and adults consuming milk contaminated with Dieldrin, we can use the Estimated Daily Intake (EDI) and compare it with the Acceptable Daily Intake (ADI).

Given Data

- **Concentration of Dieldrin in milk (C)**: 3.22 µg/kg (which is 0.00322 mg/kg since 1 µg = 0.001 mg)
- **Body Weight (BW)**: 15 kg for children, 50 kg for adults
- **Intake Rate (IR) of milk**: 0.6 kg/day for children, 0.75 kg/day for adults
- **Acceptable Daily Intake (ADI)**: 0.0001 mg/kg body weight

Step 1: To calculate the Estimated Daily Intake (EDI)

The Estimated Daily Intake (EDI) is calculated using the formula:

$$\mathrm{EDI} = \frac{C\text{x IR}}{BW}$$

where:

- C = Concentration of Dieldrin in milk (mg/kg)
- IR = Intake rate of milk (kg/day)
- BW = Body weight (kg)

For Children (15 kg body weight):

$$\mathrm{EDI}_{\text{children}} = \frac{0.00322\times 0.6}{15} = \frac{0.001932}{15} = 0.0001288 \text{ mg/kg body weight/day}$$

For Adults (50 kg body weight):

$$\mathrm{EDI}_{\text{Adult}} = \frac{0.00322\times 0.75}{50} = \frac{0.002415}{50} = 0.0000483 \text{ mg/kg body weight/day}$$

Step 2: Compare EDI with ADI to Assess Risk

Now, to compare the EDI to the ADI of 0.0001 mg/kg body weight/day:

For Children:

$$\textbf{Risk}_{\text{Children}} = \frac{\text{EDI Children}}{ADI} = \frac{0.0001288}{0.0001} = 1.288$$

For Adult:

$$\textbf{Risk}_{\text{Adult}} = \frac{\text{EDI Adult}}{ADI} = \frac{0.0000483}{0.0001} = 0.483$$

Step 3: Interpretation

Children: The risk ratio is 1.288, which is **greater than 1**. This indicates that the exposure exceeds the acceptable daily intake, suggesting a potential health risk.

Adults: The risk ratio is 0.483, which is **less than 1**. This indicates that the exposure is within the acceptable limit, suggesting a lower risk.

Children consuming this milk may be at a health risk since their EDI exceeds the ADI for Dieldrin.

Adults are at a lower risk since their EDI is below the ADI.

General discussion

The health risks associated with the consumption of milk contaminated with Dieldrin, a persistent organochlorine pesticide, can be quantitatively assessed using mathematical modelling. This involves calculating the Estimated Daily Intake (EDI) of Dieldrin for both children and adults and comparing these values to the Acceptable Daily Intake (ADI). The calculations reveal that children face a higher risk due to their EDI exceeding the ADI, while adults remain within safe limits. This disparity highlights significant public health implications, particularly for vulnerable populations such as children.

The EDI for children, calculated as 0.0001288 mg/kg body weight/day, exceeds the ADI of 0.0001 mg/kg body weight/day, resulting in a risk ratio of 1.288. This indicates that children consuming contaminated milk may be at a health risk, as their exposure surpasses the acceptable threshold (Gill et al., 2020). In contrast, the EDI for adults is 0.0000483 mg/kg body weight/day, yielding a risk ratio of 0.483, which is below the ADI, suggesting a lower risk for this demographic (Abbassy et al., 2021). The implications of these findings are critical, as children are more susceptible to the adverse effects of pesticide exposure due to their developing bodies and higher relative intake of food and liquids compared to their body weight (Negatu et al., 2021).

Research indicates that pesticide residues, including Dieldrin, can lead to various health issues, including neurological disorders, developmental delays, and even cancer (Yao et al., 2021). The chronic exposure to such contaminants in food products poses a significant public health concern, particularly in regions where regulatory measures may be insufficient (Maigari et al., 2021). For instance, a study in Ethiopia noted that many dairy farm owners sell products from animals treated with pesticides without adhering to withdrawal periods, thereby increasing the risk of consumer exposure (Negatu et al., 2021). This situation is echoed in other studies, which emphasize the need for stringent monitoring and regulation of pesticide residues in food products to safeguard public health (Wahab et al., 2022).

Furthermore, the presence of Dieldrin in milk not only affects individual health but also raises broader public health concerns. The accumulation of such pesticides in the food chain can lead to long-term health consequences for populations, particularly in developing countries where agricultural practices may not prioritize food safety (Demsie, 2024). The World Health Organization has estimated millions of cases of pesticide poisoning annually, underscoring the urgency of addressing pesticide residues in food (Maigari et al., 2021).

The mathematical modelling of Dieldrin exposure through contaminated milk reveals significant health risks, particularly for children. This necessitates immediate action to enhance regulatory frameworks, promote safer agricultural practices, and raise public awareness regarding the dangers of pesticide residues in food. By addressing these issues, it is possible to mitigate the health risks associated with pesticide exposure and protect vulnerable populations.

Conclusion

The presence of pesticide residues in food animals poses significant public health risks that warrant urgent attention. The associated health risks are extensive, affecting not only individual health but also broader public health outcomes. By implementing stronger regulatory measures, promoting safer agricultural practices, and increasing public awareness, it is possible to reduce the health risks associated with pesticide residues and protect vulnerable populations from their harmful effects.

Public Health Recommendations:

Based on the results, the study called for stricter regulation and monitoring of pesticide use in Niger State, particularly in agricultural practices that directly impact livestock feed.

It advocated for the promotion of sustainable agricultural practices, including the adoption of Integrated Pest Management (IPM) to reduce reliance on harmful chemical pesticides.

The study also recommended raising public awareness on the health risks of pesticide residues in food products and urged for regular screening of milk and other animal products to protect consumers, especially vulnerable populations like children.

Declarations

Declaration of Ethical Compliance:

All authors of this manuscript have thoroughly read, understood, and fully complied with the ethical guidelines outlined in the "Ethical Responsibilities of Authors" as presented in the Instructions for Authors. We affirm that the research and content of this paper adhere to the highest standards of integrity, ensuring that all applicable ethical principles are observed and upheld.

Ethics approval and consent to participate

The study received ethics approval (approval number MLF/2024/025) from the Committee on Animal Use and Care of the Ministry of Livestock and Fisheries in Niger State, Nigeria. Prior to sample collection, the researchers obtained informed consent from the farm managers overseeing the study site. The consent form clearly explained the study details and potential benefits. The farm managers voluntarily signed the form, agreeing to participate**.**

Not applicable

Availability of data and materials

All relevant data for the study are within the paper and also available as supporting information.

Competing interests

The authors have declared that there are no competing interests.

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Authors' contributions

The research project was a collaborative effort involving several authors who made important contributions at different stages. Hussaini A. Makun and Hadiza M. Lami were responsible for the initial conception and design of the study. They played a key role in shaping the overall research approach and objectives. Adama Y. John, Micheal O. Mecheal, Evuti H. Aliyu, and Nma A. Bida served as the principal investigators. They designed the data collection tools, carried out the data gathering process, and conducted the analysis and interpretation of the results. Monday O. Micheal and Nma A. Bida provided oversight and supervision for the laboratory aspects of the research. Evuti H. Aliyu and Nma A. Bida took the lead in drafting the initial version of the manuscript. Hussaini A. Makun, Hadiza M. Lami, Adama Y. John, and Nma A. Bida then carefully reviewed and revised the article, providing important intellectual input and suggestions to strengthen the final paper. All authors read and approved the completed manuscript prior to submission, ensuring consensus on the content and findings presented. This collaborative effort, with each author contributing their expertise at different stages, was crucial to the successful execution and reporting of this research project.

Consent to Publish

We, the authors of the manuscript titled *"*Assessment of Pesticide Residue Practices and Public Health Implications in Agro-Pastoral Communities of Niger State, Nigeria *,"* hereby give our full and unequivocal consent to publish this work in the *Journal of Research Direction:One Heallth*.

This manuscript represents our original research work, and we confirm that it has not been submitted or published elsewhere, in whole or in part. We believe that this research contributes significantly to the field of environmental science, particularly in the context of understanding the biodegradation of pesticides in agro-pastoral environments.

We affirm that all necessary ethical approvals have been obtained for this study, and we have adhered to the highest standards of research integrity throughout the process. Furthermore, all authors have reviewed and approved the manuscript's content and agree with the decision to submit it for publication.

By consenting to the publication of this manuscript, we acknowledge that the *Journal of One Health: Research Direction.* holds the right to distribute and reproduce the work, in accordance with the journal's policies. We also understand that the journal may edit the manuscript for clarity and consistency with its publication standards, provided that the content and meaning of the research are not altered.

We appreciate the consideration of our work for publication in your esteemed journal and look forward to contributing to the advancement of knowledge in environmental science and pollution research.

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Data Availability Statement

The raw data that support the findings of this study are not publicly available due to . institutional and ethical restrictions. However, they can be made available upon reasonable request from the corresponding author.

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